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Antimisting Fuel Degrader Investigation

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Prepared by
General Electric
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16. Abstract

An investigation was made of the General Electric F101 augmentor fuel pump to perform as a degrader of AMK fuel. The test plan specified the pump be run at three power conditions in four separate tests. Test 1 was run utilizing Jet-A fuel to calibrate system parameters and set fuel flow rates at idle (1200 pounds per hour), cruise (5500 pph) and takeoff (16000 pph). Test 2 utilized AMK fuel at the same fuel flow rates as were used for Jet-A fuel, the pump being in its standard configuration. Tests 3 and 4 utilized AMK fuel at the same conditions, however, the pump was successively modified to enhance AMK degradation. Fuel samples were taken at the pump inlet and discharge. Pump inlet and discharge pressures and temperatures were monitored. Special sampling procedures were utilized to prevent the inadvertant degradation of the AMK fuel during the sampling process. Very high degradation levels of the AMK fuel was achieved at the cruise power condition for all three pump configurations. Somewhat reduced degradation levels were achieved at the idle and takeoff modes depending upon which pump configuration was being tested.

Further testing was conducted to try to enhance degradation at the idle mode in the standard pump configuration. These results showed very high levels of degradation when the pump speed was increased by 12 percent.

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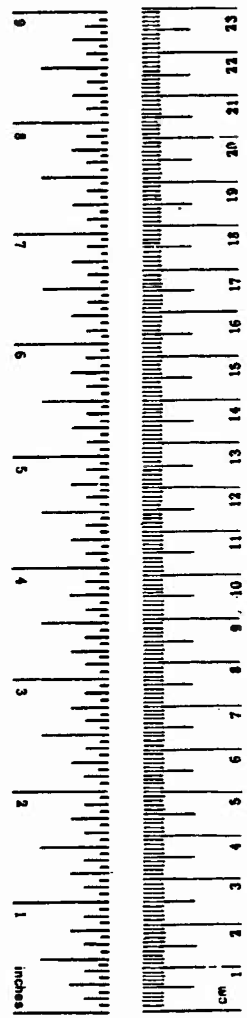
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

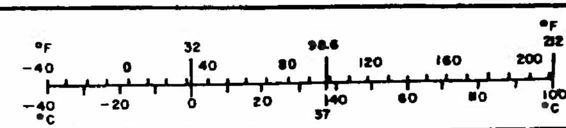
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This report describes the results of an Antimisting Fuel Degrader Investigation conducted by the General Electric Company Aircraft Engine Business Group. This project was sponsored by the Federal Aviation Administration, Contract DOT-FA79NA-6043, under the direction of Mr. Gary Frings, FAA Project Engineer. The technical guidance, support and keen interest of Mr. Frings and the FAA Technical Center were particularly instrumental in the successful completion of this project.

The work reported herein was performed under the technical direction of George Coffinberry, Principle Engineer, Fluid and Energy Transfer Systems. Bruno Alexander was the General Electric Company Program Manager.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

In 1978, the US Federal Aviation Administration (FAA) and the British Ministry of Defense (MOD) undertook a joint effort to investigate the use of Imperial Chemical Industries (ICI) fuel modifier, FM-9 or similar fuel additives as an effective means for converting jet kerosene into a safe relatively non-flammable aircraft fuel; antimisting kerosene (AMK). The FAA program under the sponsorship and direction of the FAA Technical Center, Atlantic City, New Jersey has as its objective the completion of sufficient investigation and technical work to make a Federal Aviation Regulation (FAR) recommendation by 1984. This recommendation may lead to the required use of AMK for civil gas turbine powered aircraft, lead to its required use at a later date, continue development of AMK or abandon the effort.

FM-9 has an extremely high molecular weight (over 5×10^6) and consists of long twisted molecules. The additive is mixed with Jet-A fuel in a concentration of about 0.3 percent by weight. The very long molecules of the polymer interact and intertangle with each other so as to capture the Jet-A molecules and inhibit the formation of the fine mist needed for fire propagation. Extensive experiments by the FAA and MOD including high-speed tank ruture tests, have essentially proven AMK's effectiveness as a fire-safe fuel.

However of course, this inability to burn present problems with the engine. The first and most obvious problem is light-off ignition of the engine combustor along with satisfactory combustion stability and blow-out limits. Another now recognized major problem is the blockage of fine filters and screens in the engine fuel system with the use of partially degraded AMK.

In order to overcome these engine fuel system problems, it is necessary to degrade the AMK or restore it to parent Jet-A properties. The device needed for such abundance of FM-9 degradation is referred to as a degrader.

The program and results described in this report are for an FAA Technical Center sponsored program to investigate the degrading characteristic of a high speed centrifugal fuel pump. Such a program was deemed necessary to determine the effectiveness of a pump as a one-pass fuel degrader. The General Electric F101 engine augmentor fuel pump was chosen for this investigation and the test conditions were to be based on the General Electric CF6-80A engine used on the Boeing 767 aircraft. The F101 pump is considerably oversize in terms of flow capacity, but for program economic reasons it was necessary to use an existing pump.

It would be desirable that the centrifugal pump provide a complete level of AMK degradation in a single pass through the pump. The view is based on the fact that the reliability of the centrifugal pump as the prime means for supplying fuel to the engine is inherently as good as or better than the

reliability of the gear pumps now used on the vast majority of commercial aircraft jet engines. Further, it is recognized that improvements in the technology and design of future jet engines may lead to the use of high speed centrifugal pumps.

Centrifugal pumps by virtue of their non-sliding pumping elements would be uneffected by the low lubricity of hydrotreated fuels from the more modern refineries of the future. Centrifugal pumps require no filtration as do vane or piston pumps nor do they generate contamination as do gear pumps. As a conventional main fuel pump the centrifugal is also more efficient from the standpoint of fuel temperature rise at cruise and low power engine operating points. Without any design complexity it produces less than half the fuel temperature rise of a gear pump at critical idle descent conditions. This reduction in fuel temperature rise is primarily attributed to a reduction in the recirculative flow which is characteristic of the positive-displacement fuel pump and bypassing engine control system. This saving in fuel heat sink can translate into meaningful improvement in engine specific fuel consumption (SFC) by eliminating the need for secondary air cooling for generators or similar equipment. In summary, the desired objectives for an AMK degrader are:

1. No compromise to aircraft engine reliability or safety.

2. No special operational or maintenance requirements (no human error factors).

3. No additional components.

4. No additional weight, cost, or increased SFC.

5. Compatibility with future technology and fuel properties.

The results of this program indicate that a modified centrifugal pump would ultimately meet these objectives.

DISCUSSION

This program was aimed at an investigation of the centrifugal pump as an AMK fuel degrader. For lack of any other immediately available high speed centrifugal fuel pump, the F101 augmentor pump was used for the investigation. It was apparent from the prior investigation of AMK degraders by others (References 1 and 2) that high velocity fluid shear stress could degrade AMK. However it was also recognized that to achieve highly degraded AMK in a single pass would be extremely difficult. Early work by others had also shown that with repeated passes of partially degraded fuel through the same degrading device, the degree of additional degradation was an ever-diminishing result. Hence to be meaningful, single-pass degradation was considered necessary, and the desired level of degradation had to be achieved at the pump discharge, not downstream of the flow control valve or

other throttling device. This result would then enable the consideration of the centrifugal pump as a replacement to the engine gear-type fuel pump so as to achieve flow, pressure, and degradation from a single device.

With respect to any mechanical device, there are certain power losses which must be accepted as part of the relative size of the machine. For degradation of AMK by a mechanical device it was recognized that the total magnitude of engine flow must be addressed during the tests since degradation and power requirements are not (from an engine fuel system standpoint) scalable results. Hence the flow requirements of the 48,000 pound thrust CF6-80A engine were used to establish test point conditions. Significant results from the investigation are as follows:

1. Three impeller diffusers were evaluated. It was found that reducing the clearance between the impeller and diffuser inlet improved degradation. Promoting additional interaction between the diffuser and impeller further increased degradation. A small increase in power was far less than what would be expected, particularly when the AMK is near a highly degraded state. In terms of filter-ratio (explained in detail in the text), at takeoff power conditions the results were 8.2, 3.5, and 2.3 for successive diffuser improvements. The corresponding relative horsepower demands (centrifugal pump power increase over gear pump power) were 44.8, 60.9, and 62.5. Obviously to those familiar with the problem of AMK degradation, a filter-ratio reduction from 3.5 to 2.3 at 15,637 pph flow for only 1.6 HP is encouraging.

2. As was expected the cruise condition of 5506 pph at 98.5 speed was the easiest. For this combination of modest flow and high speed the three diffusers yielded filter ratios of 1.8, 1.2, and 1.2. Corresponding relative power (centrifugal pump power increase over gear pump power) was 35.5, 61.8, and 48.3 HP.

3. The idle condition appeared to be a problem based on the initial test runs. Filter-ratios were inconsistent and all above 10. It initially appeared that the standard diffuser gave the best result. It was decided to try higher speed since the cruise results were good and at a higher flow than idle. While holding the idle flow to 1226 pph or higher in order to maintain safe fuel temperatures for the lab technician who were collecting on-line fuel samples, speed was increased in 5 percent increments. A 12-percent speed increase dropped the filter-ratio dramatically from 23.2 to 1.3 and the ratio continued to decrease to 1.05 at 90-percent of rated pump speed while the flow had increased to 3102 pph. Recheck of the original base speed (idle) filter-ratio showed that the standard diffuser was no better and probably worse than the modified diffusers. However, the important finding was that a minimum or critical speed is necessary even at idle to achieve adequate degradation. Relative power input at idle speed plus 12-percent and 1226 pph flow, was 12.1 HP.

4. Measurements were taken of pump discharge pressure pulsations and it was found that no adverse effects had been generated by the diffuser modifications. Consequently the degrading mechanism involving only fluid shear should not lead to fuel system or combustion problems. These results also showed that air or vapor evolution from the fuel was not part of the degrading mechanism.

5. Taken collectively, the results indicate that the centrifugal pump can be made into an effective degrader. Sized for the flow requirements of the engine main fuel system (41 gpm instead of 210 gpm for the F101 pump), power requirements should be reduced considerably.

COMPONENT DESCRIPTION

The pump used for this program was the General Electric F101 engine (B1 bomber version) augmentor fuel pump. The design point requirements for this pump are:

Fuel	JP-4
Speed	24902 RPM
Flow	210 GPM
Pressure Rise	1000 psid
Efficiency	63%
Input Power	194 HP

The pump is shown in Figure 1. As used for this AMK program, the pump incorporated a conventional high-speed centrifugal impeller and vaned diffuser. This standard diffuser is referred to as diffuser number 1.

In order to enhance the degrading performance of the pump, two diffuser modifications were evaluated. The first modification involved close clearance between the impeller tip and the diffuser inlet. This was diffuser number 2. Diffuser number 3 involved a technique aimed at increasing secondary flow interaction between the impeller and diffuser. All of these pumping mechanisms are conventional, involving only the pressure gradients and flow fields that normally exist in pumps of this type. No attempt was made to introduce cavitation or air evolution from the fuel. Fuel throttling at sea level pressure usually involves evolution of air. As an aircraft cruises at high altitude, air and high-boiling-point fuel vapors are driven off in the fuel tanks. As discussed later in this report, there were no unusual pressure fluctuation, which is evidence of the lack of air or vapor evolution at the discharge of the centrifugal pump.

A fundamental objective of this effort is to replace the conventional gear pump with a high speed centrifugal pump. Figure 2 shows the conventional CF6-80A gear type fuel pump. Note the weight and size of the gear pump compared with the centrifugal pump shown in Figure 1.

TEST SETUP AND PROCEDURE

TEST SETUP

The pump test setup is shown schematically in Figures 3 and 4. Figure 5 shows the completed setup in Cell 46, Building 703, of the General Electric Systems and Component Development test area.

The pump was mounted to and driven by a 24,902 RPM (100-percent) gearbox which in turn was driven by a 4528 RPM (100-percent) 1000 HP dynamic drive.

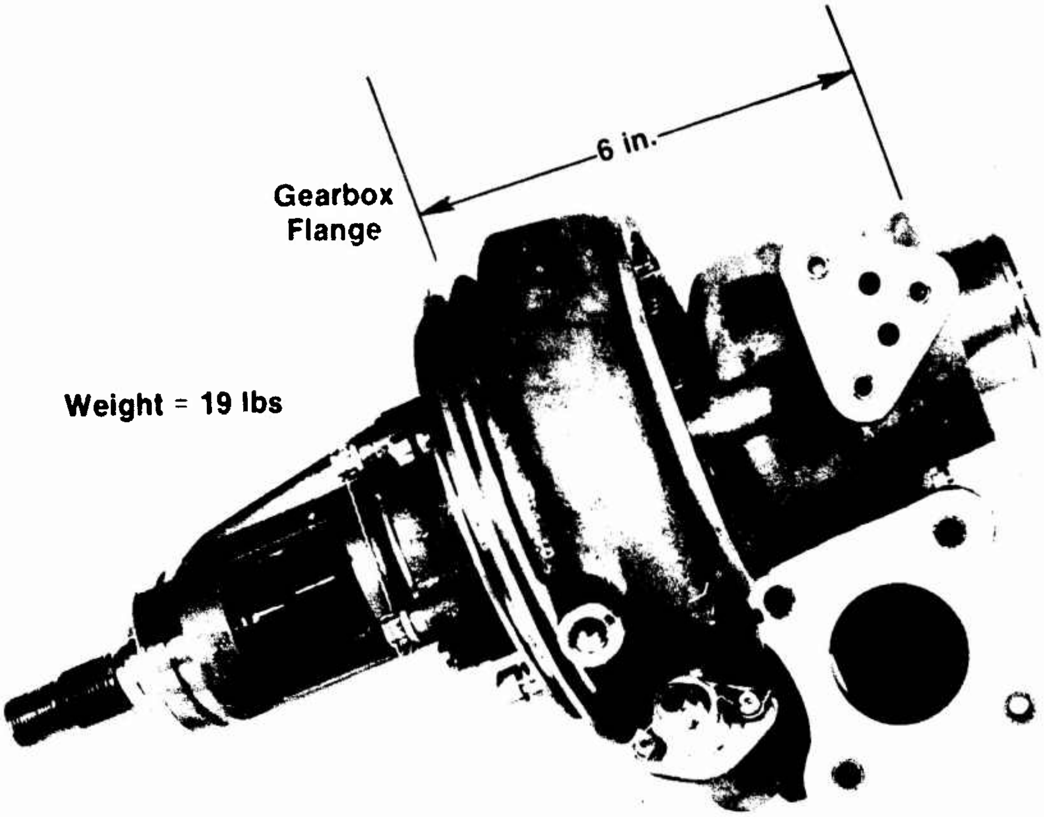


FIGURE 1 F101 AUGMENTOR FUEL PUMP

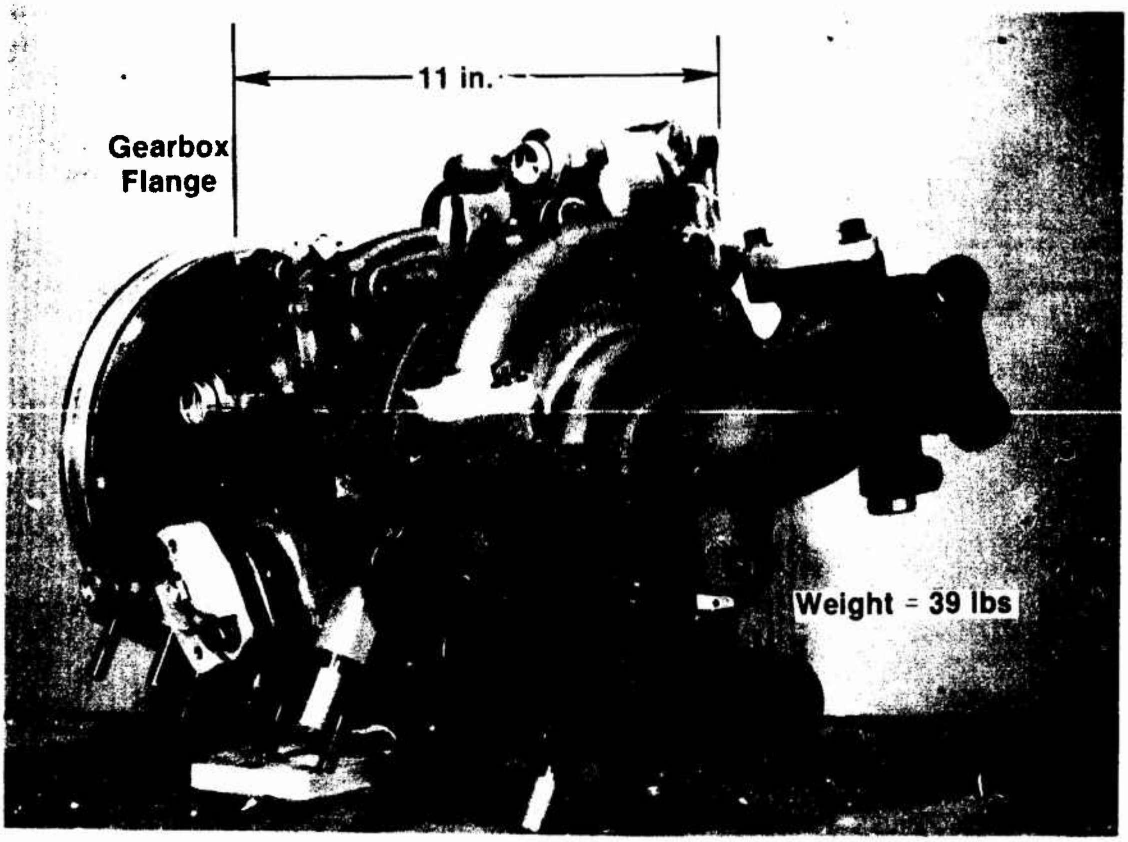


FIGURE 2. CF6-80A FUEL PUMP

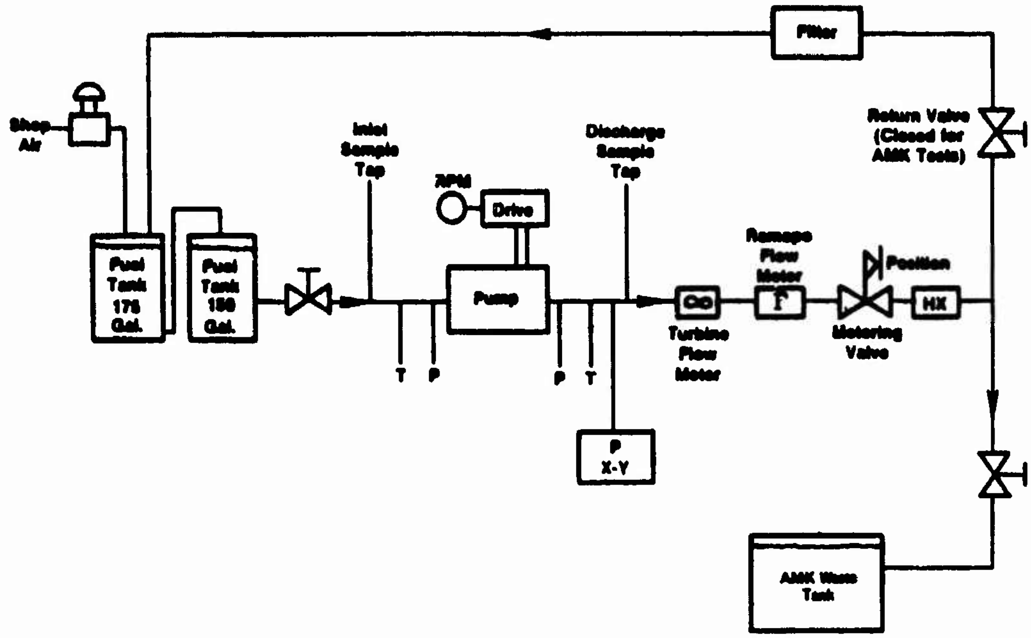


FIGURE 3. TEST SETUP SIMPLIFIED SCHEMATIC

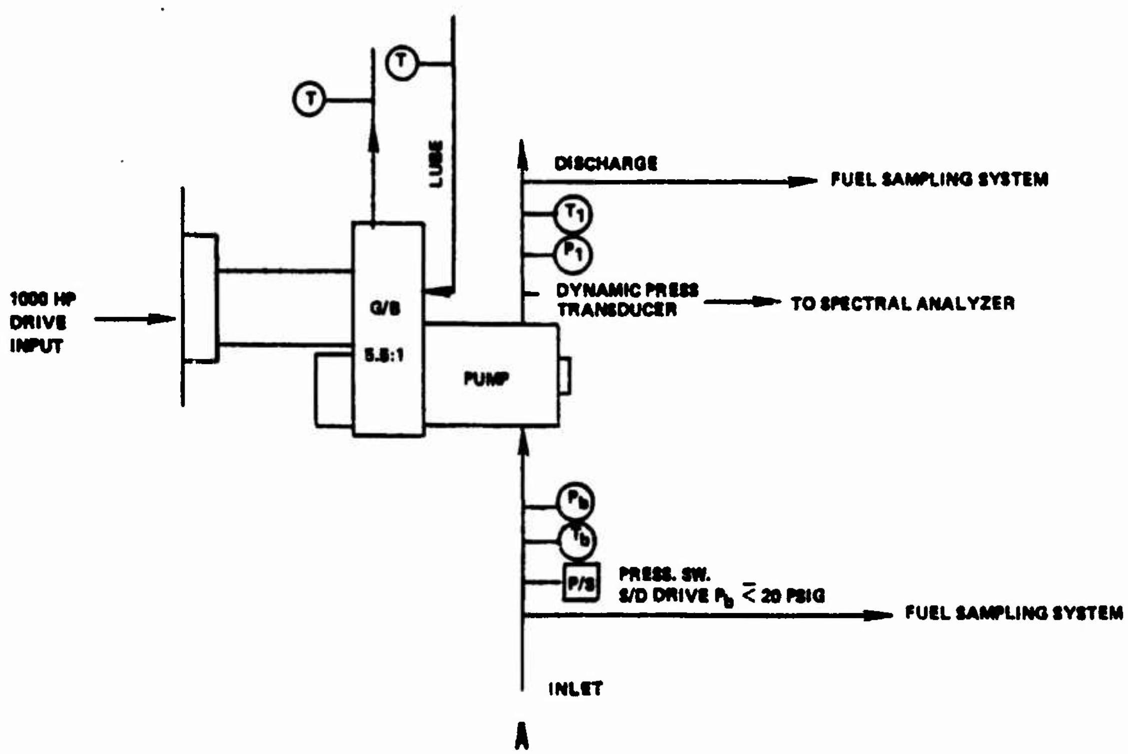
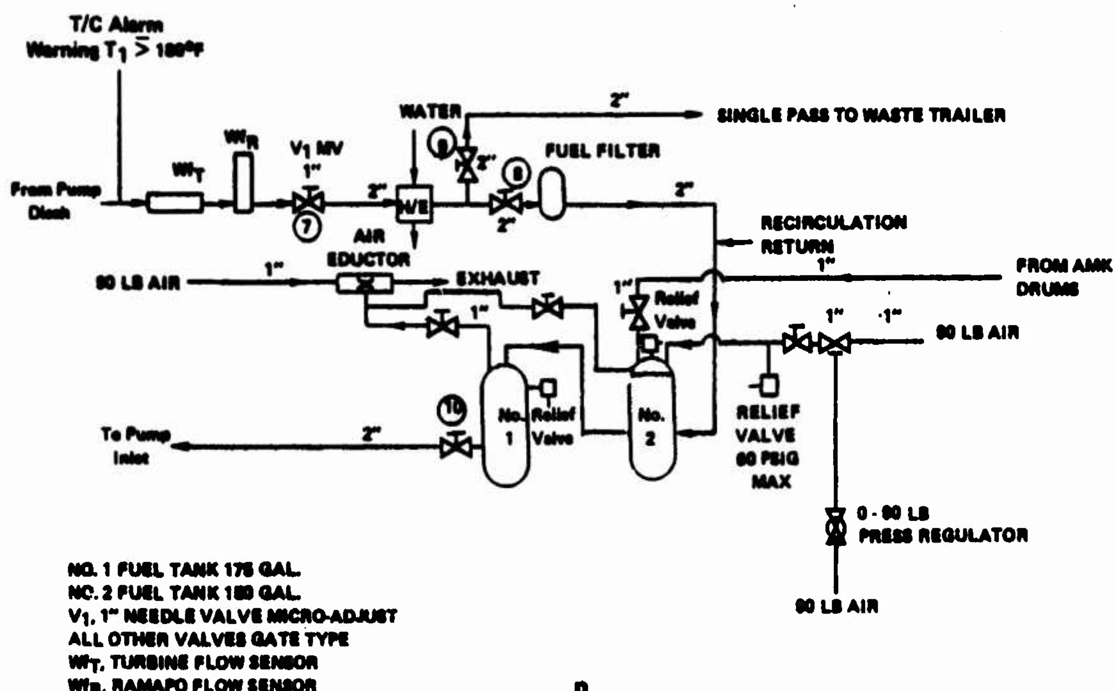


FIGURE 4. TEST SETUP DETAIL SCHEMATIC (1 of 2 pages)



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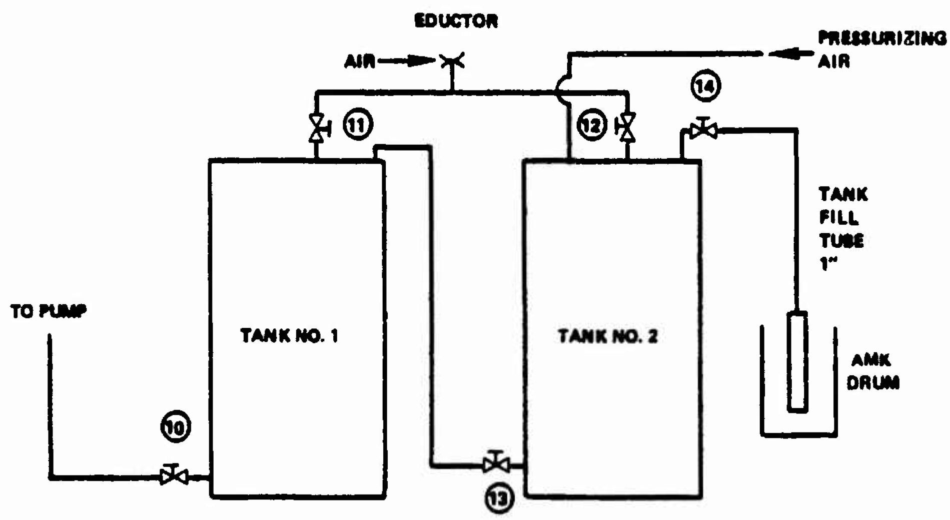

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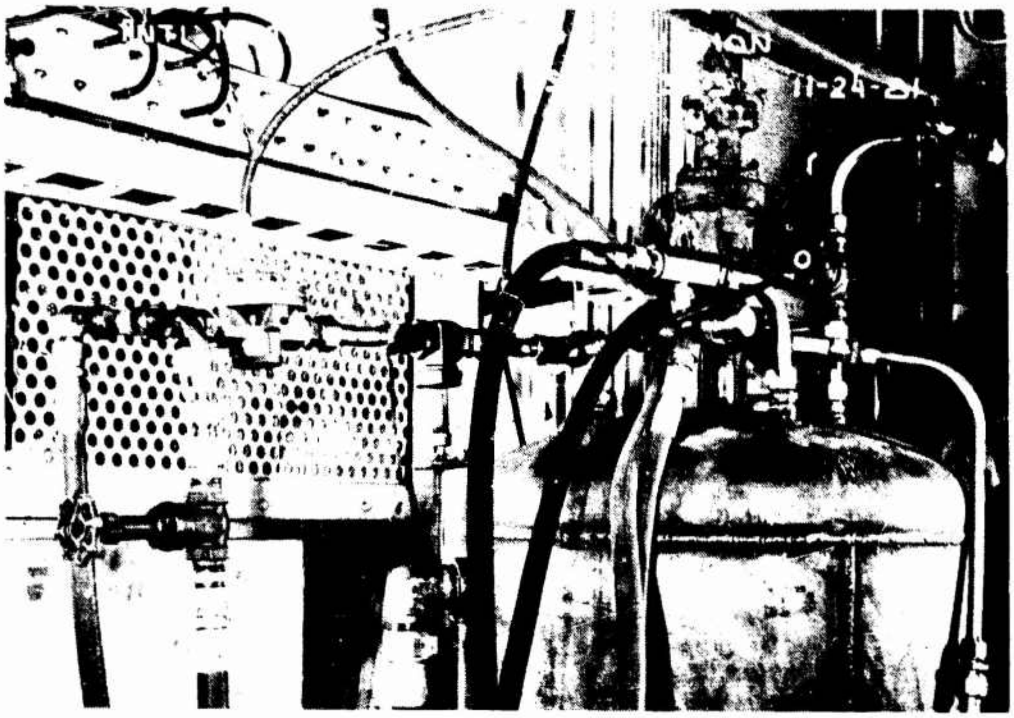
FIGURE 4. TEST SETUP DETAIL SCHEMATIC (2 of 2 pages)



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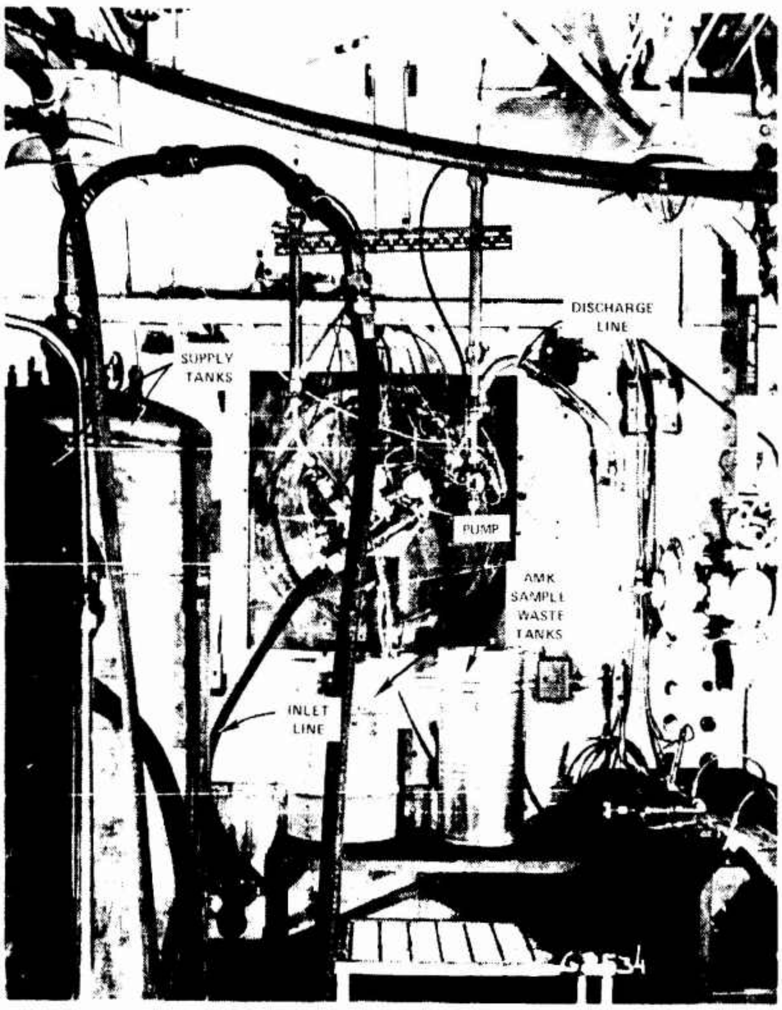

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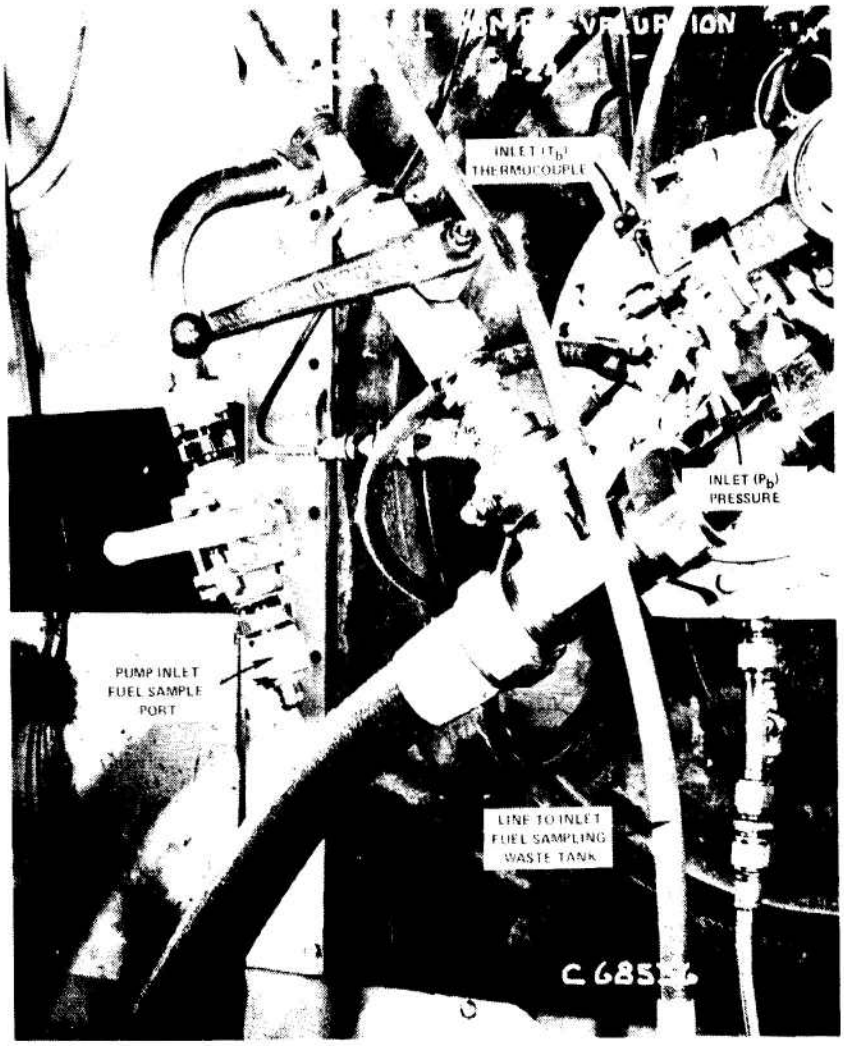
FIGURE 5. CELL 46 AMK
TEST SETUP

C



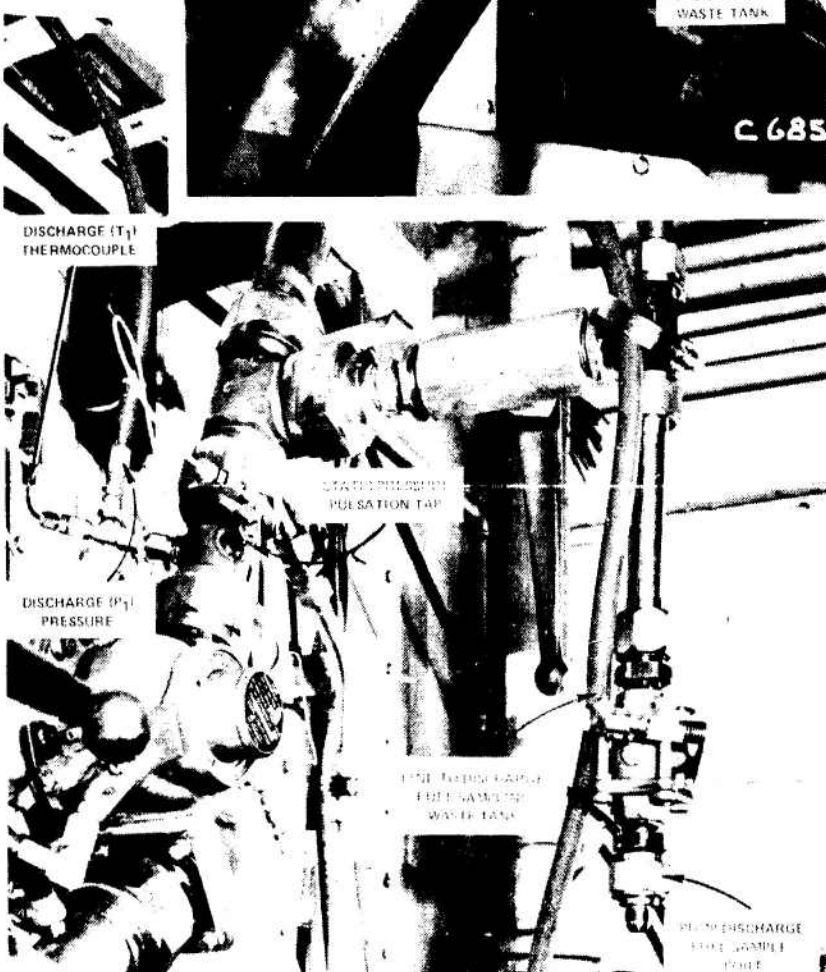


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FIGURE 5. CELL 46 AMK TEST SETUP (Continued)

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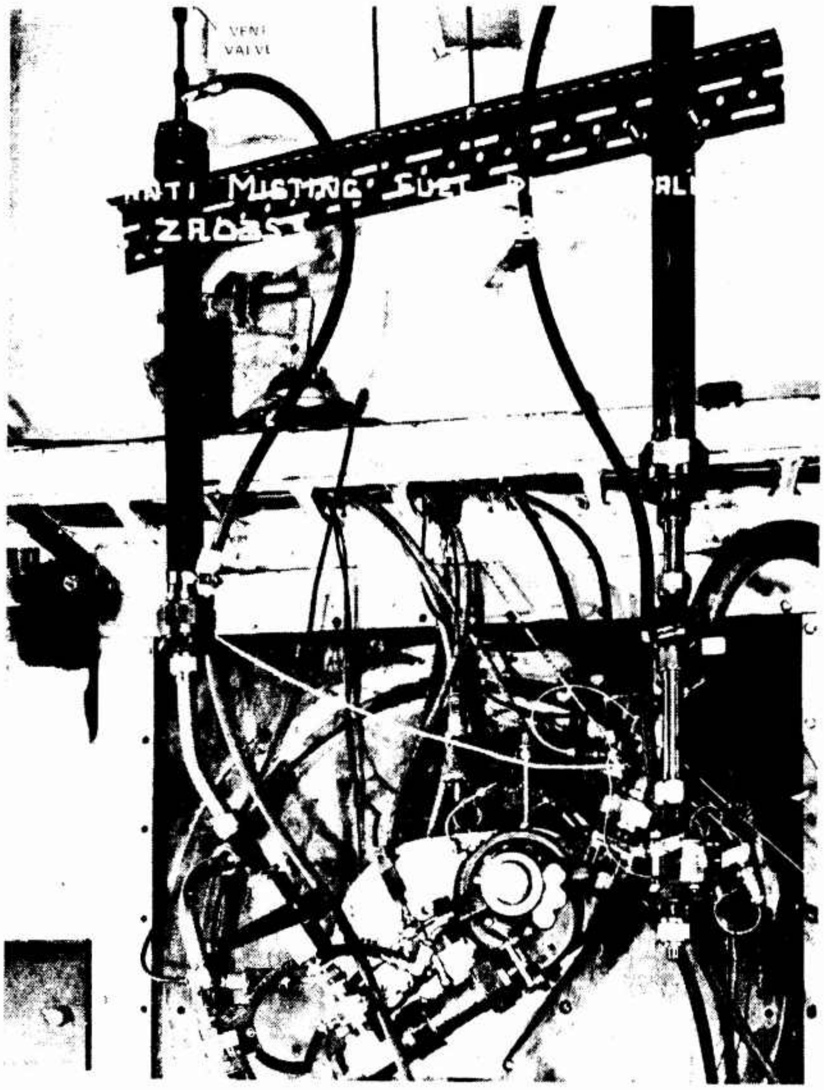

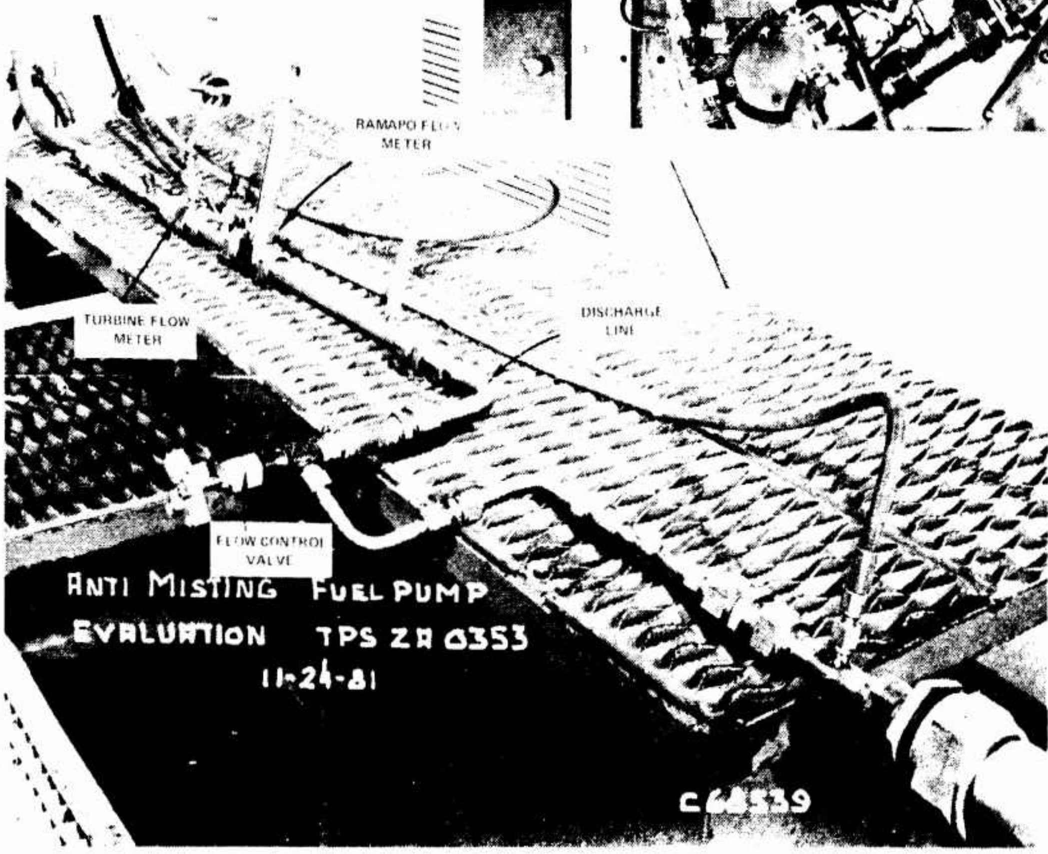

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FIGURE 5.
CELL 46 AMK
TEST SETUP
(Concluded)

Two fuel supply tanks (175 gal and 150 gal) were arranged in series to supply enough fuel for completion of a test sequence (Idle, Cruise, and Takeoff). For initial practice runs with Jet-A, fuel was recirculated through a heat exchanger back to the supply tanks. For final Jet-A and AMK runs, the fuel made only one pass and was discharged to a waste tank trailer.

Fuel flow was controlled by a micro-adjustment hand valve located in the discharge line. The valve shown in Figure 5 incorporated a color-coded stem-position indicator permitting pre-setting of the valve prior to making a test run. The fuel flow meters also shown in Figure 5 were located upstream of the flow-control valve. A reed-type (Ramapo) and a turbine flow meter were used in series.

An air eductor was used to evacuate the fuel supply tanks for filling with fresh fuel. Shop air (up to 90 psig) was used to pressurize the supply tanks and in turn the pump inlet during the tests. The arrangement is shown in Figure 4.

All steady-state data was log-recorded from gauge readings. Oscillograph-trace Sanborn recorders were used to record the same data as backup to gauge readings. Pump discharge dynamic pressure was measured with a Kulite transducer, recorded on magnetic tape and printed out on an X-Y plotter after passing through a spectral analyzer. Instrumentation equipment is shown in Figures 6 and 7. All gauges and other instruments were calibrated prior to the AMK program tests and data accuracy was to the same limits as normally required for engine development and certification tests. Figure 7 shows the instrumentation console used to obtain the dynamic pressure readouts and X-Y plots of pressure pulsations versus frequency. The location of instrumentation taps are shown in Figures 4 through 5.

TEST PROCEDURE

The test was conducted in two parts. First, practice runs were made using recirculated and single-pass Jet-A to assure that there were no problems with the setup, pump, instrumentation or test procedure. It was also necessary during the practice runs to determine the fuel metering valve position for each test point. Only pump speed, not flow, was adjusted when running with AMK. Each of the three diffusers was checked in determining metering valve positions because of slight difference in pump pressure rise at the same mass flow rate. Table 1 shows the valve positions used for the test. The practice runs also served as a means for refining the AMK fuel sampling procedure. It was important to have this procedure well practiced so as to avoid any repeats with a limited quantity of AMK and to assure the quality of the samples. All aspects of the test were checked before going to AMK. A complete test series was run using Jet-A and each of the three diffusers. The test was run with single-pass fuel and fuel samples were taken just as they would be for AMK.

FIGURE 6. CELL 46 CONTROL CONSOLE

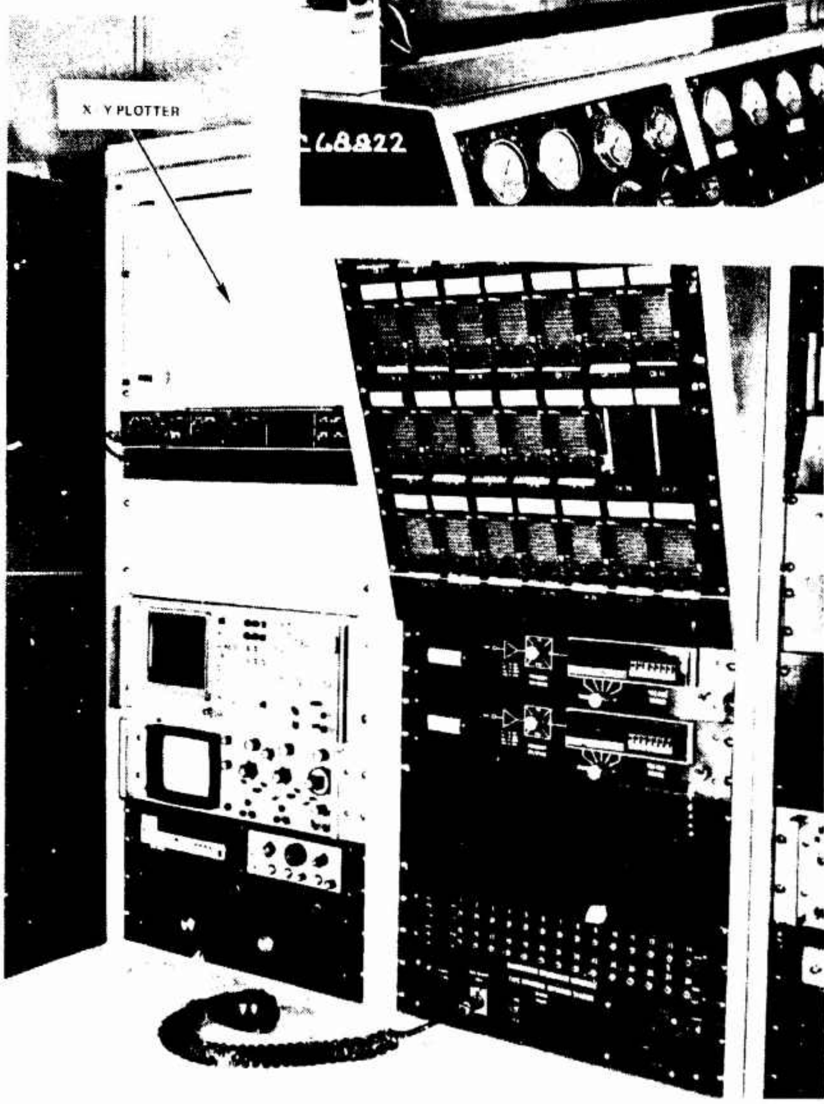


FIGURE 7. SPECTRAL ANALYSIS CONSOLE

TABLE 1. DISCHARGE METERING VALVE POSITION

Point No.	Diffuser No. 1	Diffuser No. 2	Diffuser No. 3
1	3.7 Black	3.5 Black	3.5 Black
2	2.5 Black	1.3 Black	2.2 Black
3	1.3 Full Open	4.5 Silver	1.3 Full Open

Table 2 shows the steady-state run points used for the test. All runs were made at ambient fuel temperature. Actual pump testing began on Dec. 3 and was completed on Dec. 11, 1981. For AMK tests, the supply tanks were partially evacuated and AMK was drawn from the fuel drums. A portion of each fuel lot was mixed in the supply tanks. Table 3 lists the fuel usage for the entire program. The fuel was drawn from the 50-gal AMK drums using the following procedure. See Figure 4C.

TABLE 2. TEST CONDITIONS

Point No.	Condition	Pump Speed (RPM/%)	Pump Flow (PPH)	Inlet Pressure (psig)
1	Ground Idle	16634/66.8	1226	40
2	Cruise	24528/98.5	5506	40
3	Takeoff	26022/104.5	15637	40

TABLE 3. AMK FUEL USAGE

Date	Time	RMH Fuel Batch No.	Quantity (Drums)(1)	Applicable Fuel Sample No.
12/7/81	08:00	1-177	1	6
		1-180	3-1/2	7
		1-181	3	8
12/7/81	09:35	1-177	1/2	10
		1-180	2-1/2	11
		1-181	2-1/2	12
12/7/81	13:30	1-177	1/2	14 & 1A
		1-180	2	15 & 2A
		1-181	2-1/2	16 & 3A
12/11/81	09:00	1-213	8	4A
				5A
				17
				18

(1)Drum = 330 pounds (50 gal) AMK.

1. Valves 10 and 12 were closed.

2. Valve 14 was opened and the air eductor vacuum system was turned on.

3. After filling Tank No. 1, valves 11 and 13 were closed and valve 12 was opened.

4. After filling Tank No. 2, valves 12 and 14 were closed. Valve 13 was then opened prior to starting the test.

The No. 1 diffuser was installed in the pump while it was mounted to the drive gearbox. The system was then filled with AMK and pressurized to 40 psig. Static fuel samples were taken at the pump inlet and discharge. The pump was brought to idle speed and flow was set. Inlet and Discharge samples were taken. The pump was brought to cruise speed and flow was set. Inlet and discharge samples were taken. The pump was brought to Takeoff speed and flow was set. Note in all cases, flow was set by discharge valve position not flow meter reading. Inlet and discharge samples were taken. This completed the first AMK run sequence using the No. 1 diffuser. The second and third run sequences were performed in the same manner using diffusers No. 2 and No. 3. Static samples (40 psig) were taken before each run.

After completing the planned test of the three diffusers, it was decided to repeat the idle point at higher pump speeds in an attempt to achieve better filter-ratio results. Because the No. 1 diffuser appeared at first to offer the best idle results, it was chosen for this test. As it turned out, repeat of the No. 1 diffuser at Idle was no better than the No. 2 or No. 3 diffusers, but slight speed increase was found to be effective. This fourth test sequence followed the same procedure as the first three. A second shipment of ICI AMK was used for the fourth test sequence. No attempt was made to remove the remainder of first-shipment AMK from the supply tanks or system. After completion of all tests, an AMK sample was taken from the supply tank as it was being drained. The system was then, for the first time, flushed with Jet-A. The tank AMK sample was checked for filter-ratio and water content. All of the AMK was used in a single pass through the pump and test setup. After use, all AMK was then sent to the General Electric plant boiler for disposal. All of the AMK fuel samples were sent to the FAA Technical Center after filter-ratio tests had been completed.

FUEL SAMPLING PROCEDURE

The basic objective of the fuel sampling procedure was to obtain AMK samples at the immediate inlet and discharge of the pump while it was running at test-point conditions. This had to be done without throttling or degrading the AMK fuel. With the pump discharge line at 1000 psi, this meant that throttling would have to take place downstream of the sample collection vessel, not at the inlet to the vessel. Also two-position ball valves would be needed to avoid valve restriction and high fuel velocities through these isolation valves.

The fuel sampling setup can be seen in Figure 4B, C, D and E. The setup is shown schematically in Figure 8. Two (2) inch lines joined to the pump inlet and discharge. One (1) inch lines joined the inlet and discharge

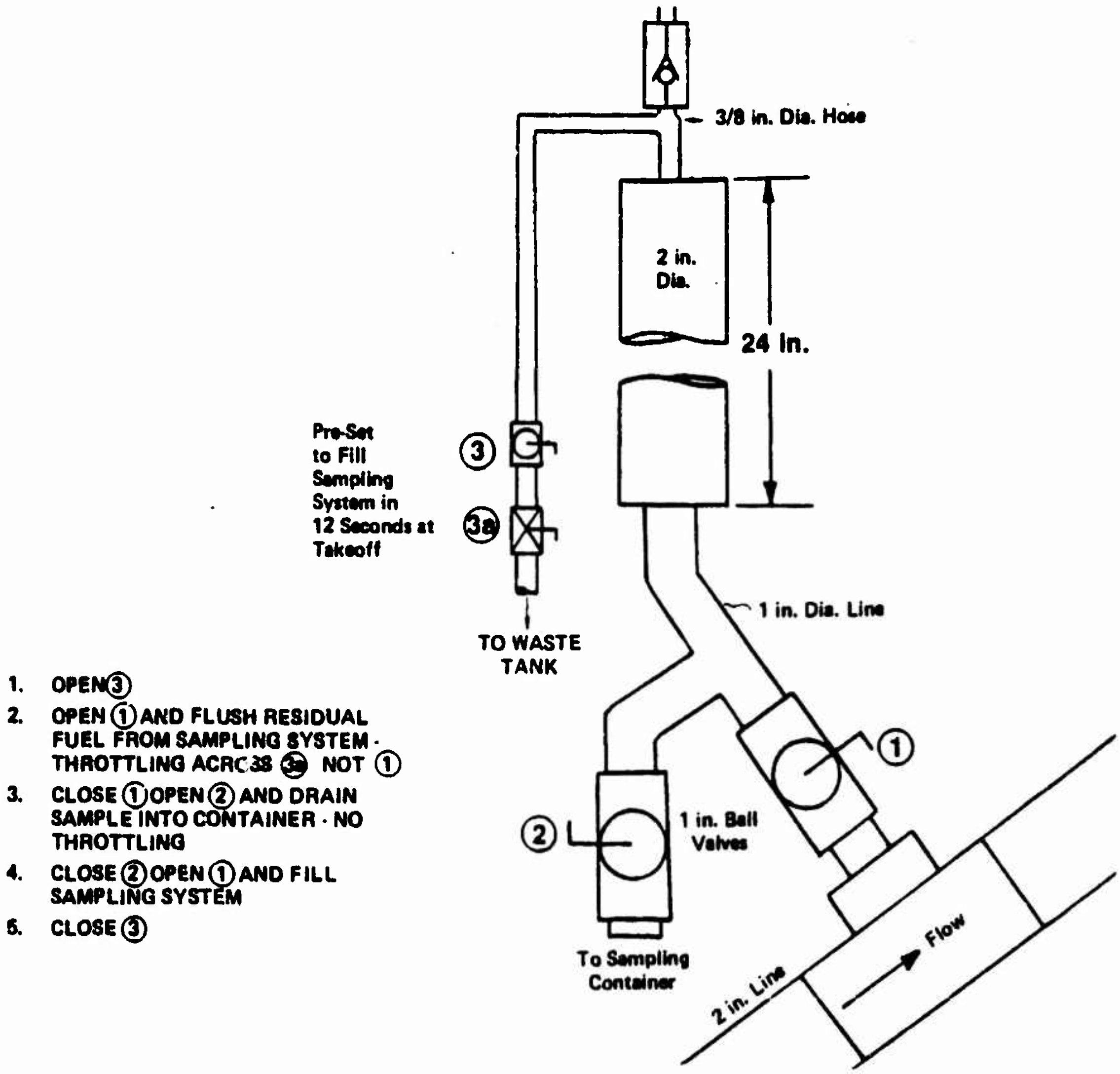


FIGURE 8. ON-LINE AMK FUEL SAMPLING SYSTEM

fuel sampling taps to 2-inch by 24-inch fuel collection vessels. On the CF6-80 engine, all lines and restrictions downstream of the pump (into fuel control) are one-inch or smaller. Consequently the flow resistance of the sampling system based on line size was no more than that which would occur on the engine upstream of any fuel filters or screens. However, fuel velocities into the sampling system were much less than would occur on the engine. The test procedure called for a filling rate (into 2-inch by 24-inch vessel) at maximum takeoff pressure of 12 seconds. The velocity in the one-inch line would be less than one foot per second. On the engine at 15,637 pph, the velocity would be 18 feet per second. Hence, no throttling of the AMK sample could occur to a degree anywhere near the degree inherent with the engine system.

Both static and running-pump samples were taken. The procedure for obtaining static samples was as follows:

1. With recirculation valve 8 (see Figure 4B) closed, the entire system was pressured to 40 psig. Valve 9 was opened to purge any residual fuel from the system, then valve 9 was closed.

2. Sampling system valve 3A was open and preset for a 12-second (takeoff point) fill rate. Valves 1 and 2 were closed. Waste tanks valve 3 was then opened.

3. With the system at 40 psig, pump inlet and discharge sampling valve 1 (Figure 3) was opened. Note, the discharge sample was always taken before the inlet sample. At least 2-quarts (over 150 percent of sample vessel volume) was allowed to flush through the sampling system.

4. Valve 1 was closed. Valve 2 was opened and a sample was collected in a new clean one quart steel sample can. Valve 2 was closed, valve 1 opened, and the sample was refilled.

The procedure for obtaining running-pump samples was as follows:

1. The pump speed was set at steady-state test conditions.

2. Valve 3A remained preset for a 12-second (takeoff point) fill rate. Valves 1 and 2 were closed. Valve 3 was opened.

3. Valve 1 was opened for 60 seconds at takeoff and cruise test points and 120 seconds at the idle test point. This assured about 5 times the sampling vessel volume would flush the discharge sampling system at takeoff and cruise, and about 3 times the system volume would flush the sampling system at idle. Only one complete flush (one system volume) would occur at the 40 psig inlet tap. However, in all cases nearly one additional volume of fresh inlet fuel was necessary to refill the sample vessel after fuel was drained into the sample can.

4. Valve 1 was closed. Valve 2 was opened and a sample was collected in the one-quart sample can. Valve 2 was closed, valve 1 was opened, and the sample vessel was refilled.

The procedure worked well and was fast enough to permit on-line sampling using a minimum amount of AMK. In addition to assuring that the samples were not subject to degradation by throttling, a vent valve at the top of the sample vessel controlled the rate of drainage into the one-quart fuel sample cans.

FILTER-RATIO PROCEDURE

Filter-ratio flow-times were determined using a test apparatus and pre-cut 17-micron screens provided by the FAA Technical Center. The apparatus shown in Figure 9 and schematically in Figure 10 consisted of a glass graduate with a parallel standpipe. A 17 micron filter screen (see Figure 9) was placed in a metal holder at the bottom of the graduate.

The principle of operation is to flow a precise quantity of fuel at a consistent gravity head and fluid temperature through a precise cross-sectional area of screen. The time for the total amount of fuel to pass through the screen is measured. A fast filter-ratio flow-time indicates a lower viscosity characteristic of degraded FM-9. When the flow-time of AMK is compared to the flow-time for the base Jet-A to which the FM-9 was originally added, the filter-ratio is established. Filter-ratio is equal to flow-time for AMK divided by flow time for base Jet-A.

At low values of filter-ratio (less than 1.5) more discriminating techniques than filter-ratio may be employed. These other techniques involve measurement of the apparent transition velocity between laminar and turbulent flow (equivalent to critical Reynolds Number for Newtonian fluids) or the slope of the flow versus ΔP line in the pseudo-laminar and pseudo-turbulent flow regimes for non-Newtonian AMK. Because these other techniques are considerably more time consuming and costly than filter-ratio, they were not used during this preliminary investigation of the centrifugal pump as a potential AMK degrader.

The procedure used to obtain filter-ratio flow times was as follows:

1. A new or cleaned 17-micron screen was placed in the holder.

2. The fuel sample was heated or cooled in a water bath to precisely 22°C (72°F).

3. The graduate was filled to overflowing (into catch basin) and allowed to stabilize for 1.5 to 2.0 minutes.

4. The cork was removed from the bottom of the graduate permitting the fuel sample to drain into a collection vessel.

5. Using a stop watch, the time in seconds for the miniscus of the fuel to pass the upper and lower marks on the parallel standpipe was recorded.

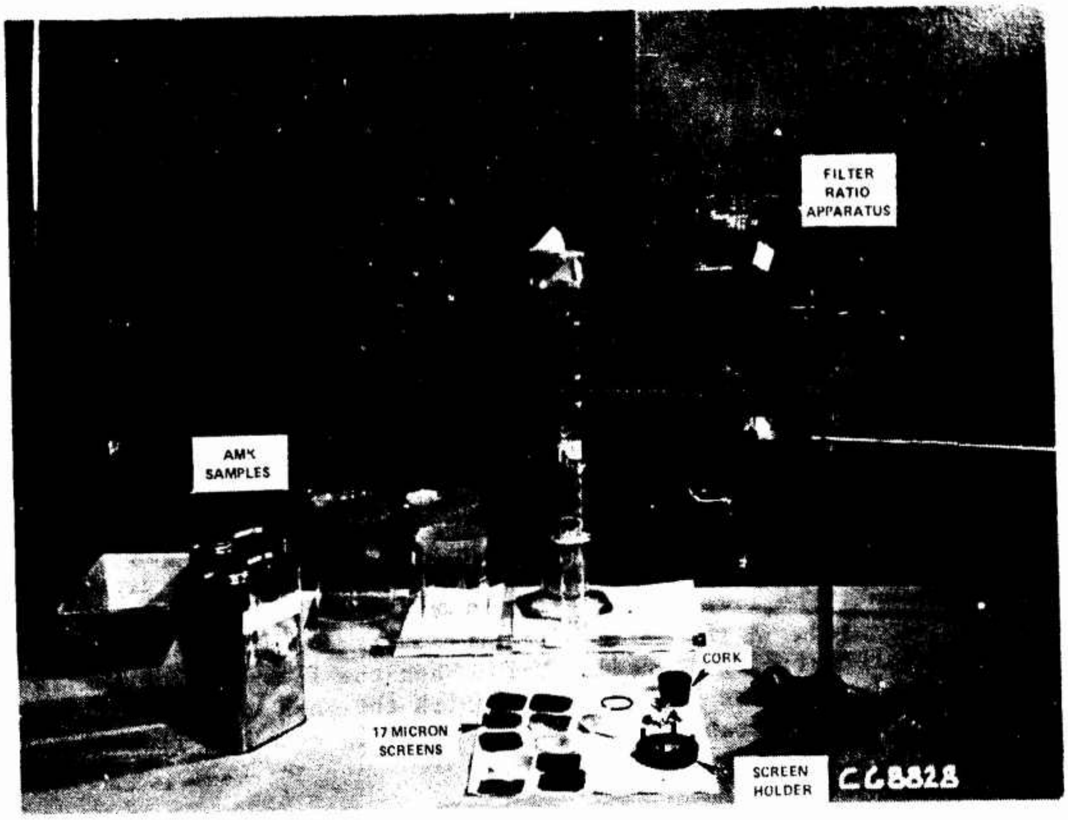


FIGURE 9. FILTER-RATIO TEST SETUP

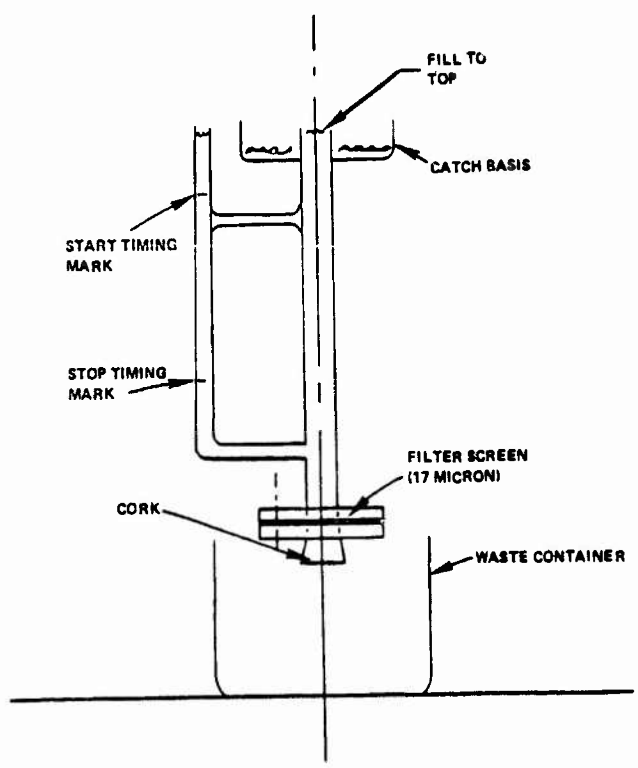


FIGURE 10. FILTER-RATIO TEST APPARATUS

6. After each use, all equipment was disassembled and cleaned thoroughly with acetone and allowed to dry.

7. The base Jet-A was checked each day of testing to determine repeatability of the filter-ratio reference.

All filter-ratio measurements were taken in a lab setup adjacent to the pump test cell. The procedure was demonstrated by FAA Technical Center Engineers to GE Engineers and Lab Technicians at Evendale on November 11, 1981 prior to the pump tests.

RESULTS

Interpretation of the test results from this program is focused on the following issues:

1. The ability of a centrifugal pump to degrade AMK.

2. Improvements in a centrifugal pump design within the constraints of this initial effort, which might improve degradation performance.

3. The effect of pump speed and flow on degradation performance.

4. The accuracy of the simple filter-ratio technique as a means for determining degrader performance.

5. The difference in power required to pump AMK relative to Jet-A.

6. The power required to pump and degrade AMK simultaneously and the effect of this power on engine specific fuel consumption (SFC).

AMK DEGRADING CAPABILITY

FILTER-RATIO. This issue is addressed first because it forms the basis for interpreting the majority of the other results. Since one measures the time for a known quantity of fluid to pass through an imperfect dimensional body (screen) one is also measuring the relative flow resistance of the screen. Shown in Figure 11 are the results in terms of flow-times, for the same Jet-A fuel to flow through several different screens. Using the ICI base Jet-A (RMH 11005) for the first test series, it was found that 13 different flow times were determined solely as a function of the differences between one piece of 17 micron screen and another; all cut from the same original sheet of screen. The standard deviation for this data is 0.48 seconds from an average time of 4.30 seconds. This represents an 11.1-percent variation in the base value used to determine filter-ratio. For the second test series and ICI fuel shipment, only two checks were made of the base Jet-A (also RMH 11005) with an average flow-time of 3.32 seconds.

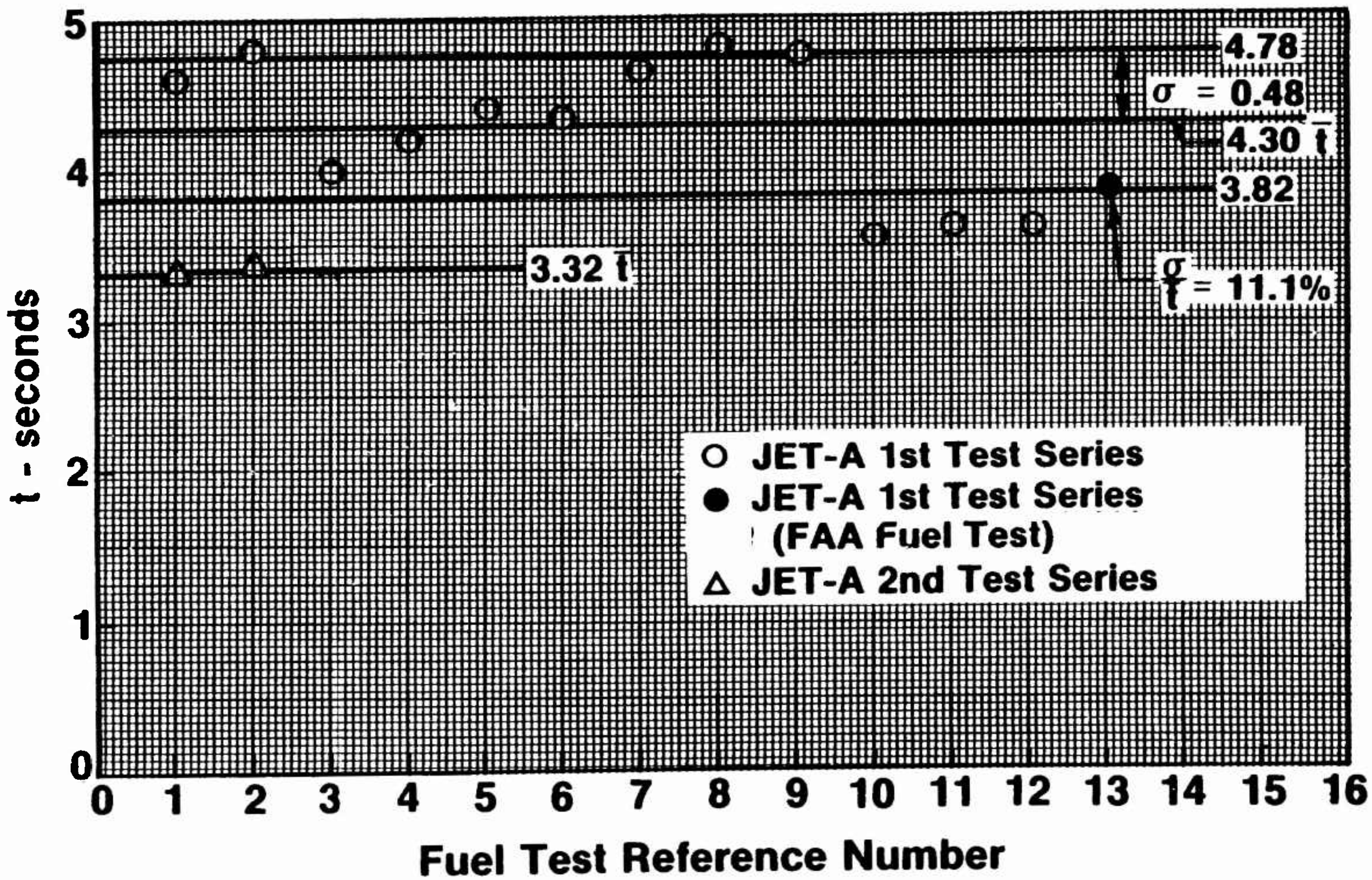


FIGURE 11. FILTER FLOW-TIMES FOR BASE JET-A

In order to consider this issue further, the GE Fuels and Combustor Lab selected an arbitrary mix of screens and measured their effective flow areas. This was done with the airflow calibration apparatus shown in Figure 12. Each screen was microscopically examined and then checked for airflow as a function of differential pressure. The results are shown in Figure 13. Each screen was tested with the direction of flow reversed. Identifier A followed by A indicates the same screen with reverse flow. The results of 20 calibration test shows 17.2 percent variation of the standard deviation from the average. Hence both the Jet-A and airflow data indicate that filter-ratio results obtained without using the exact same screen for AMK samples and Jet-A base fuel, can only be interpreted on the basis of average values. More precise techniques could be adopted in the future using the same screen for the AMK sample and the base fuel.

Figure 14 shows the filter flow-times using different screens for all of the static and pump inlet samples during the first test series. Table 4 provides precise interpretation of these points relative to the pump test. The most consistent values appear to lie between 200 and 325 seconds. Using the average base Jet-A time of 4.30 seconds this equates to a filter ratio of 61 which is reasonable for undegraded AMK. Values above 325 (filter ratio of 76) might be attributed to marked variation in screen characteristics. This data suggests no interpretations other than that the pump inlet received essentially undergraded AMK at a minimum filter-ratio of 46.5 (200 second flow time).

Figure 15 shows the same type of data as Figure 14. These results are from the second test series. The average value appears to lie around 500 seconds giving a filter ratio of 150; high indeed. A significant observation from the data shown in Figures 14 and 15 is the total lack of consistency between high flow-times for inlet and discharge samples and the same samples rechecked at a later date. It can then be concluded on the basis of all static samples and pump inlet samples that the pump inlet received undergraded AMK throughout the test, but that the filter-ratio technique using different screens appears insensitive to highly undegraded AMK.

Figure 16 shows filter flow-times for pump discharge fuel samples obtained during the first test series. These results show that reasonably close agreement was obtained for at least two or more measurements of filter flowtime using fuel samples corresponding to cruise and takeoff test points. This agreement existed in spite of the use of different screens and a long (10 day) storage of the fuel samples before repeat measurements were taken. In the case of idle test points, however, where only minimal AMK degradation occurred, there was poor repeatability of filter flow-times. Note that repeat flow-times are in agreement only at reference number 1 where filter-ratio is 11.0.

The same trends in filter flow test repeatability appeared during the second test series as shown in Figure 17. Whenever the degrading effect was marginal (high filter flow-time) the filter-ratio technique exhibited poor repeatability. It may be that gell formation is an accelerating process similar to screen blockage from dirt or ice. As the first small regions of the screen are blocked, through-flow is dependent on a ever-diminishing open area. Hence the concentration of contaminant (perhaps gel) in the remaining

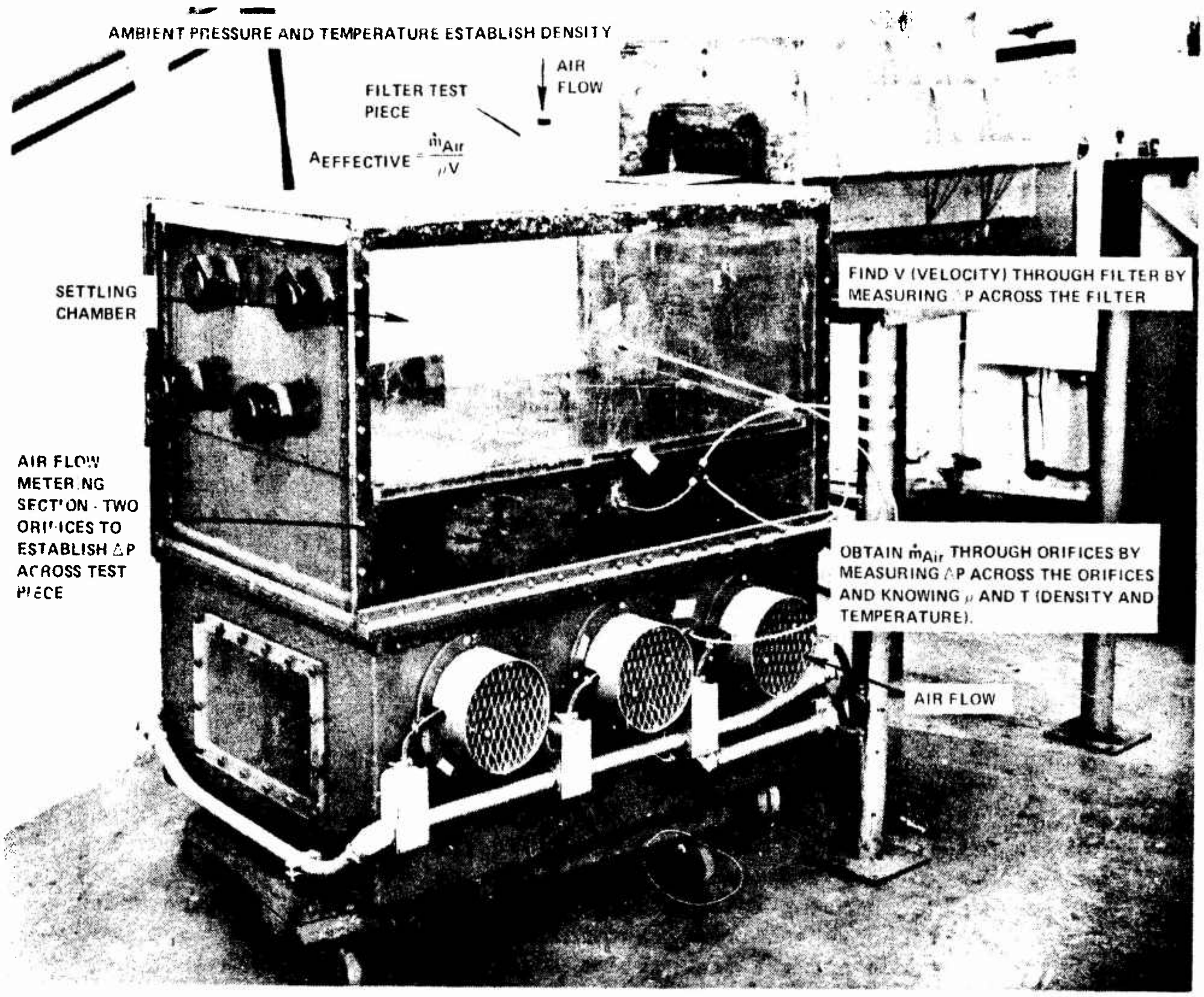


FIGURE 12. AIR FLOW CALIBRATION APPARATUS

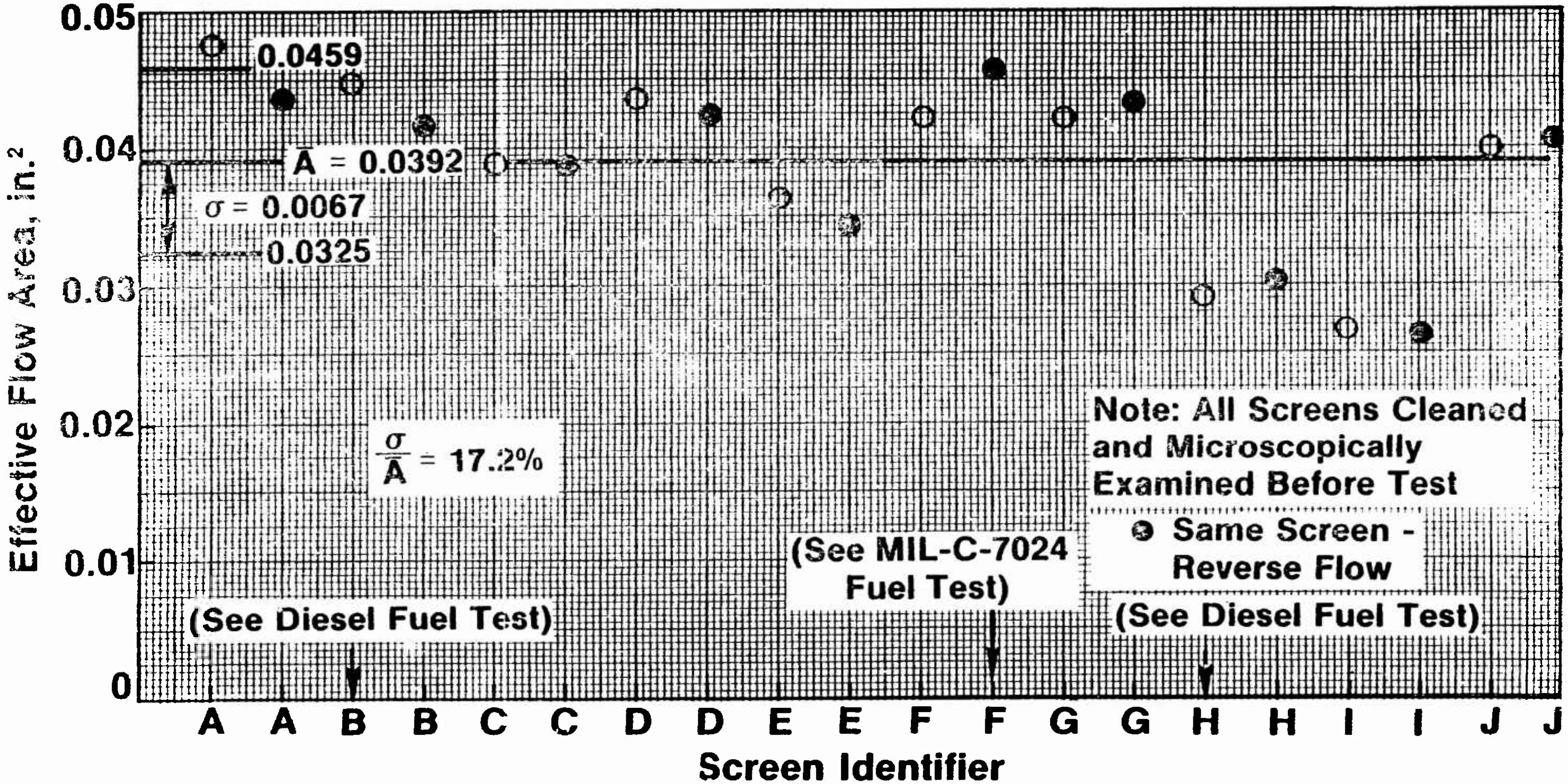


FIGURE 13. AIR FLOW CALIBRATION OF FILTER SCREENS

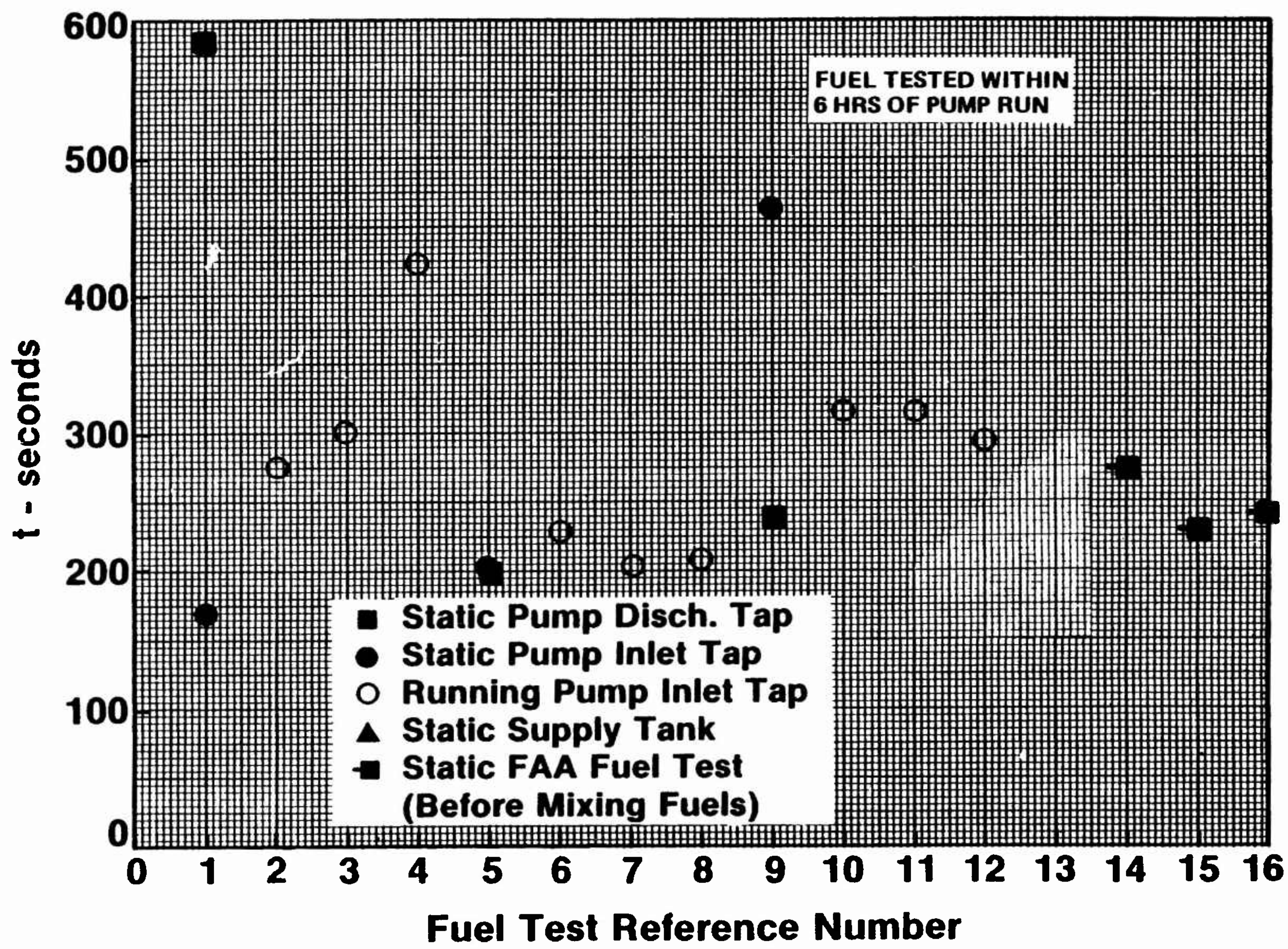


FIGURE 14. FILTER FLOW-TIMES FOR UNDEGRADED AMK - 1st TEST SERIES

TABLE 4. FILTER-RATIO TEST RESULTS

Date	Time of Day	Fuel	Fuel Sample No.	Report Reference Fig. No.	Report Reference Pt. No.	Flow Time (Seconds)	Remarks
11/12/81		Jet-A	RMH 11005	11	13	3.86	FAA Test at GE
11/12/81		AMK	1-177	14	14	272.2	FAA Test at GE
11/12/81		AMK	1-180	14	16	240.6	FAA Test at GE
11/12/81		AMK	1-181	14	15	228.5	FAA Test at GE
12/7/81	10:00	Jet-A	RMH 11005	11	1,2	4.6, 4.8	1st Base Fuel
12/7/81	11:00	AMK	5I	14	1	170.2	Static Inlet
12/7/81	11:15	AMK	5D	14	1	584.6	Static Discharge
12/7/81	13:30	AMK	6I	14	2	276.6	Diffuser #1 - Idle
12/7/81	13:45	AMK	6D	16	1	45.0	Diffuser #1 - Idle
12/7/81	14:00	AMK	7I	14	3	300.8	Diffuser #1 - Cruise
12/7/81	14:15	AMK	7D	16	2	4.8	Diffuser #1 - Cruise
12/7/81	14:20	AMK	8I	14	4	423.6	Diffuser #1 - Takeoff
12/7/81	14:25	AMK	8D	16	3	23.3	Diffuser #1 - Takeoff
12/7/81	14:30	AMK	9I	14	5	203.7	Static Inlet
12/7/81	14:45	AMK	9D	14	5	201.6	Static Discharge
12/7/81	15:00	AMK	10I	14	6	230.2	Diffuser #2 - Idle
12/7/81	15:15	AMK	10D	16	4	115.0	Diffuser #2 - Idle
12/7/81	15:30	AMK	11I	14	7	202.0	Diffuser #2 - Cruise
12/7/81	15:45	AMK	11D	16	5	4.4	Diffuser #2 - Cruise
12/7/81	16:00	AMK	12I	14	8	206.6	Diffuser #2 - Takeoff
12/7/81	16:15	AMK	12D	16	6	13.2	Diffuser #2 - Takeoff
12/7/81	16:35	AMK	10D	16	4	75.0	Repeat Diff. #2 - Idle
12/8/81	9:00	Jet-A	RMH 11005	11	3,4	4.0, 4.2	1st Base Fuel
12/8/81	9:30	AMK	13I	14	9	462.6	Static Inlet
12/8/81	9:45	AMK	13D	14	9	238.5	Static Discharge
12/8/81	10:00	AMK	14I	14	10	315.7	Diffuser #3 - Idle
12/8/81	10:20	AMK	14D	16	7	123.6	Diffuser #3 - Idle
12/8/81	10:30	AMK	15I	14	11	313.5	Diffuser #3 - Cruise
12/8/81	10:40	AMK	15D	16	8	4.3	Diffuser #3 - Cruise
12/8/81	10:45	AMK	16I	14	12	295.4	Diffuser #3 - Takeoff
12/8/81	11:05	AMK	16D	16	9	9.6	Diffuser #3 - Takeoff

TABLE 4. FILTER-RATIO TEST RESULTS (CONTINUED)

Date	Time of Day	Fuel	Fuel Sample No.	Report Reference Fig. No.	Report Reference Pt. No.	Flow Time (Seconds)	Remarks
12/8/81		Jet-A	RMH 11005	11	6,5	4.35, 4.4	1st Base Fuel
12/11/81	10:05	AMK	1A-D	17	1	51.1	Diffuser #1 - Idle 70% N
12/11/81	10:25	AMK	2A-D	17	2	5.15	Diffuser #1 - Idle 75% N
12/11/81	10:35	AMK	3A-D	17	3	4.35	Diffuser #1 - Idle 80% N
12/11/81	10:45	AMK	4A-D	17	4	4.1	Diffuser #1 - Idle 85% N
12/11/81	11:05	AMK	5A-D	17	5	3.85	Diffuser #1 - Idle 90% N
12/8/81		Jet-A	RMH 11005	18	1	4.4	All Run With New 1st Base
12/8/81		Jet-A	RMH 11005	18	2	4.35	Fuel Through the Same Filter
12/8/81		Jet-A	RMH 11005	18	3	4.55	
12/8/81		Jet-A	RMH 11005	18	4	4.75	
12/8/81		Jet-A	RMH 11005	18	5	4.85	
12/8/81		Jet-A	RMH 11005	18	6	4.85	
12/8/81		Jet-A	RMH 11005	18	7	5.10	
12/11/81	11:15	Jet-A	RMH 11005	11	1	3.3	2nd Base Fuel
12/11/81	11:18	Jet-A	RMH 11005	11	2	3.35	2nd Base Fuel
12/11/81	11:24	AMK	17D	17	6	5.4	Diffuser #1 - Cruise
12/11/81	11:32	AMK	18D	17	7	35.8	Diffuser #1 - Takeoff
12/11/81	12:45	AMK	Supply Tank	14	13	272.1	Tank After 1st AMK Run #177-#180-#181
12/11/81	13:01	AMK	5A-I	15	5	405.9	Diffuser #1 - Idle 90% N
12/11/81	13:20	AMK	1A-I	15	1	602.7	Diffuser #1 - Idle 70% N
12/11/81	13:48	AMK	4A-I	15	4	332.5	Repeat Dif. #1 - Idle 70% N
12/11/81	14:03	AMK	1A-D	17	1	103.3	Repeat Dif. #1 - Idle 70% N
12/11/81	14:18	AMK	2A-D	17	2	3.8	Repeat Dif. #1 - Idle 75% N
12/11/81	14:26	AMK	3A-D	17	3	3.9	Repeat Dif. #1 - Idle 80% N
12/11/81	14:41	AMK	4A-D	17	4	4.1	Repeat Dif. #1 - Idle 85% N
12/11/81	14:46	AMK	5A-D	17	5	4.4	Repeat Dif. #1 - Idle 90% N
12/11/81	15:00	AMK	17D	17	6	5.3	Repeat Dif. #1 - Cruise
12/11/81	15:13	AMK	17D	17	6	5.9	Repeat Dif. #1 - Cruise
12/11/81	15:19	AMK	18D	17	7	29.1	Repeat Dif. #1 - Takeoff
12/11/81	15:25	AMK	18D	17	7	40.8	Repeat Dif. #1 - Takeoff

TABLE 4. FILTER-RATIO TEST RESULTS (CONTINUED)

Date	Time of Day	Fuel	Fuel Sample No.	Report Reference Fig. No.	Report Reference Pt. No.	Flow Time (Seconds)	Remarks
12/17/81	14:01	AMK	6D	16	1	49.3	
12/17/81	14:07/14:26	AMK	7D	16	2	12.4/7.7	
12/17/81	14:14	AMK	8D	16	3	27.9	
12/17/81	14:21	AMK	11D	16	5	4.6	
12/17/81	14:35	AMK	12D	16	6	18.9	
12/17/81	14:43	AMK	14D	16	7	88.4	
12/17/81	14:50	AMK	15D	16	8	6.75	
12/17/81	14:59	AMK	16D	16	9	10.9	
12/17/81	15:13	AMK	2A-I	15	2	477	
12/17/81	15:30	AMK	3A-I	15	3	489	
12/17/81		Jet-A	RMA 11005	11	7,8,9	4.65/4.8/ 4.75	1st Base Fuel
12/18/81	8:40	AMK	5A-I	15	5	781	
12/18/81	9:00	AMK	17I	15	6	846	
12/18/81	9:44	AMK	18I	15	7	584	
12/18/81		JP-4				1.8/1.85/ 1.95	
12/18/81		JP-4				2.1/1.95/ 1.85/2.0	
12/18/81		D-2				6.1/6.0	
12/18/81		Jet-A	RMH 11005	11	10,11,12	3.55/3.6/ 3.6	1st Base Fuel
12/18/81		JP-8				2.85/2.9	
12/18/81		Jet-A-1				3.6/3.6	
1/4/82			1	18	1	3.7	Calibration Fluid MIL-C-2074
1/4/82			2	18	2	3.7	Through Filter "F"
1/4/82			3	18	3	3.8	
1/4/82			4	18	4	3.9	
1/4/82			5	18	5	3.9	

TABLE 4. FILTER-RATIO TEST RESULTS (CONCLUDED)

Date	Time of Day	Fuel	Fuel Sample No.	Report Reference Fig. No.	Report Reference Pt. No.	Flow Time (Seconds)	Remarks
1/4/82			6	18	6	4.1	Calibration Fluid MIL-C-2074
1/4/82			7	18	7	4.1	Through Filter "F"
1/4/81			8	18	8	3.9	
1/4/82			9	18	9	4.0	
1/4/82			10	18	10	4.0	
1/4/82		D-2	1	18	1	8.6	All Run With Diesel Fuel
1/4/82		D-2	2	18	2	8.6	No. 2 Through Filter "B"
1/4/82		D-2	3	18	3	8.6	
1/4/82		D-2	4	18	4	8.8	
1/4/82		D-2	5	18	5	9.0	
1/4/82		D-2	6	18	6	9.0	
1/4/82		D-2	7	18	7	8.9	
1/4/82		D-2	8	18	8	9.2	
1/4/82		D-2	9	18	9	9.0	
1/4/82		D-2	10	18	10	8.8	
1/4/82		D-2	1	18	1	10.4	All Run With Diesel Fuel
1/4/82		D-2	2	18	2	10.6	No. 2 Through Filter "H"
1/4/82		D-2	3	18	3	11.1	
1/4/82		D-2	4	18	4	11.2	
1/4/82		D-2	5	18	5	11.3	
1/4/82		D-2	6	18	6	11.6	
1/4/82		D-2	7	18	7	11.8	
1/4/82		D-2	8	18	8	12.7	
1/4/82		D-2	9	18	9	12.6	
1/4/82		D-2	10	18	10	12.6	

Notes:
1) All tests conducted at 22°C (72°F).
2) I = Inlet Sample D = Discharge Sample

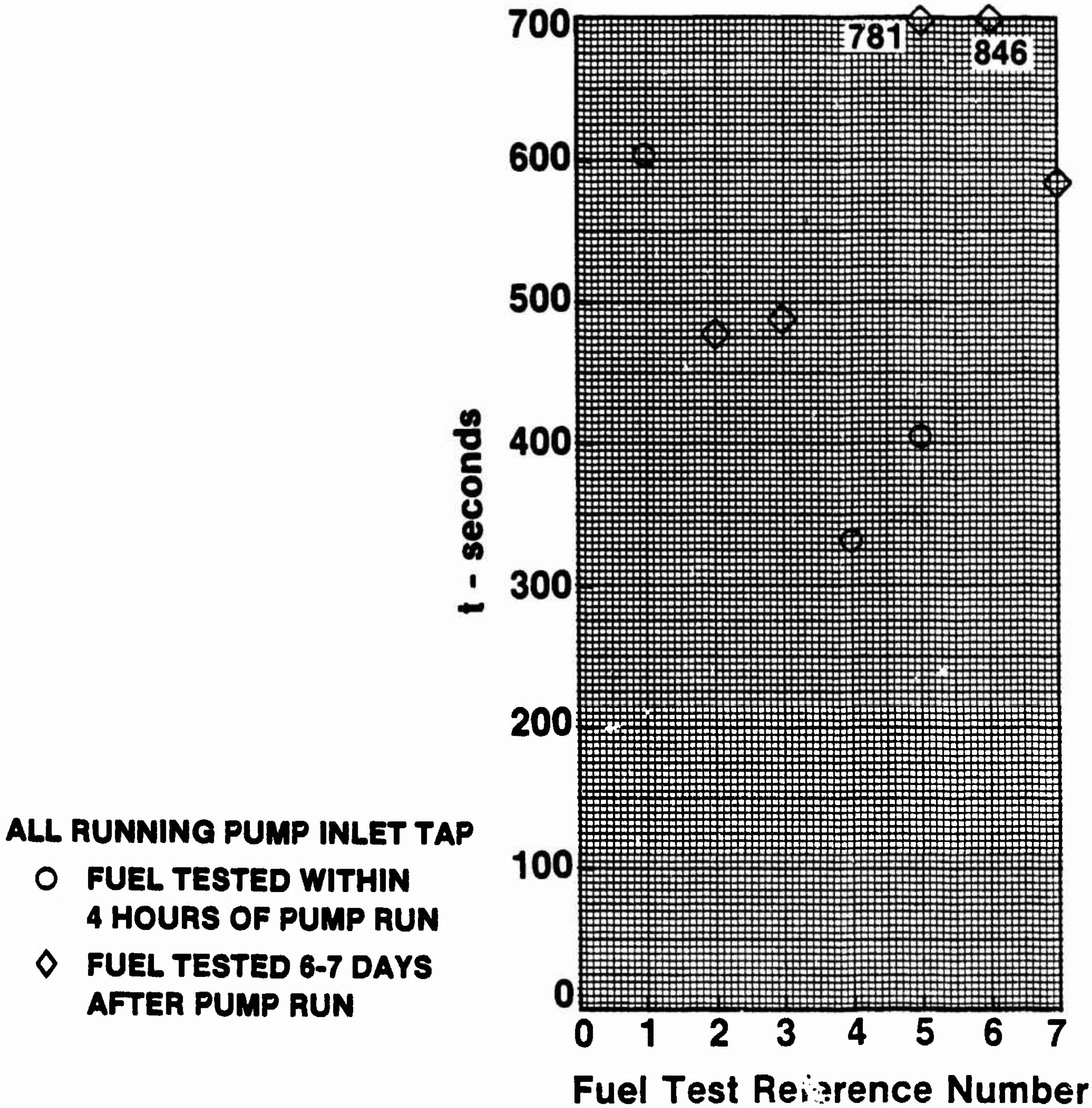


FIGURE 15. FILTER FLOW-TIMES FOR UNDEGRADED AMK - 2nd TEST SERIES

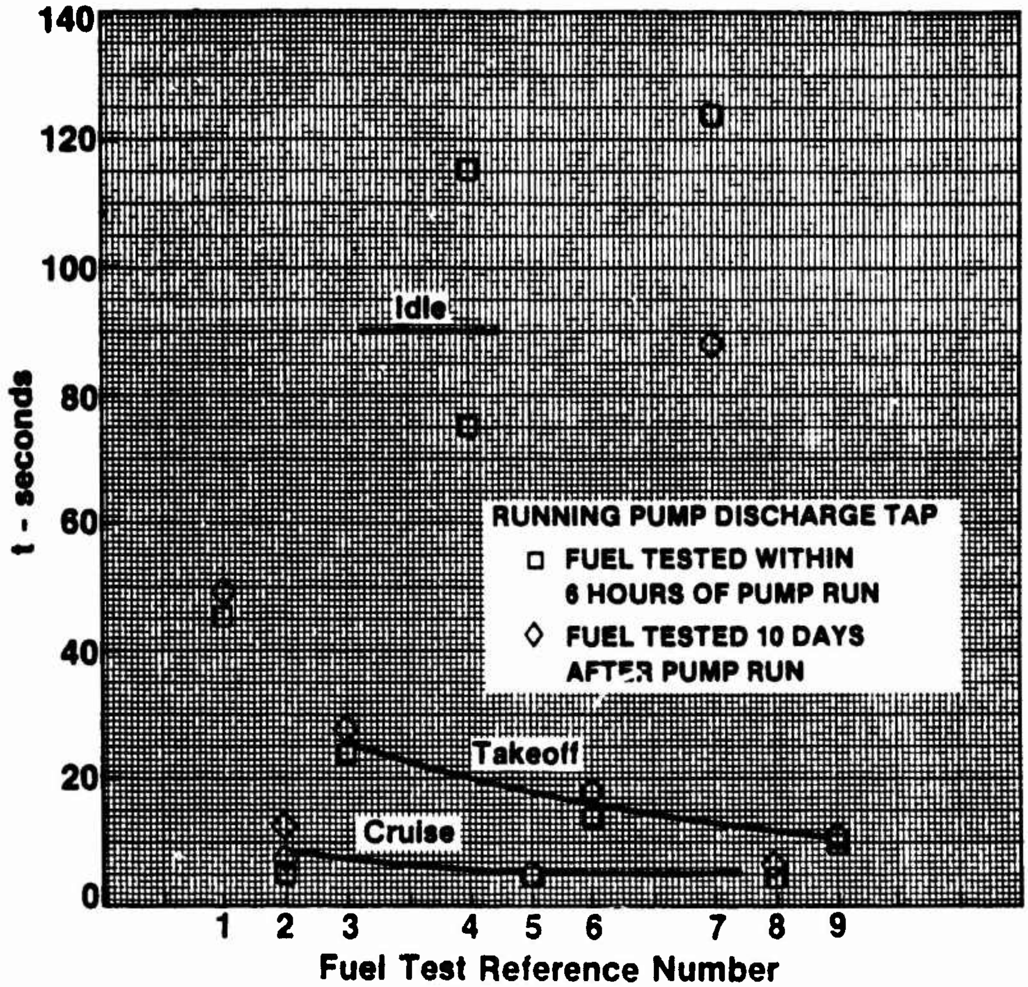
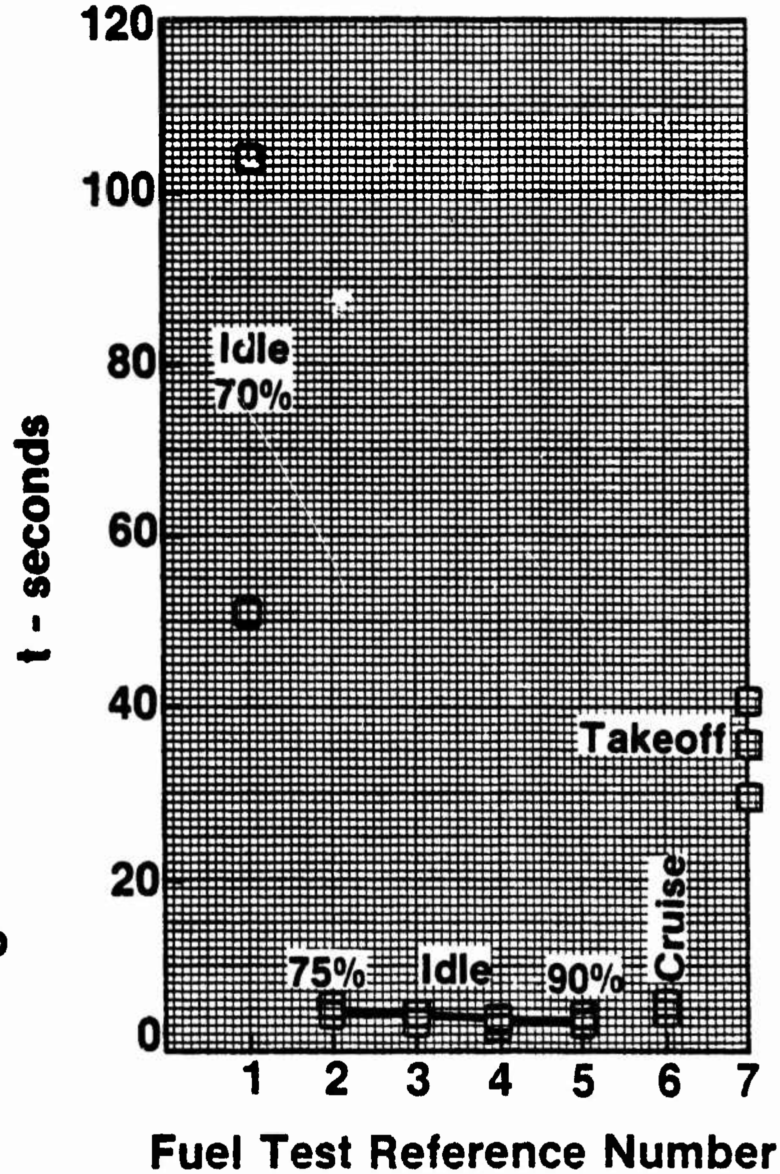


FIGURE 16. FILTER FLOW TIMES FOR DEGRADED AMK - 1st TEST SERIES



Running Pump Disch Tap

Fuel Tested Within
6 hrs of Pump Run

FIGURE 17. FILTER FLOW-TIMES FOR DEGRADED AMK- 2nd TEST SERIES

through-flow fluid increases as the screen open-area reduces. Depth filters are often used to avoid this problem and to allow the fluid to pass around a localized blockage without a reduction of the total free-flow area.

Before proceeding at this point to the actual pump results it is interesting to note another finding relative to filter-ratio. Figure 18 shows the results of filter flow-times for conventional jet fuels using the same 17 micron screens as those used for the AMK tests. Since jet fuel also contains straight-chain molecules it might be that the filter-ratio apparatus can assess the "filter-ratio" of ordinary fuels. If this is the case, then much could be learned as to the degree of AMK degradation required for the gas turbine engine. The results shown in Figure 18 were obtained from clean screens using clean fuel. For each fuel, flow-time measurements were repeated rapidly in succession without letting the screen dry. As can be seen, the flow-times continue to increase as more fresh fuel is passed through the same screen. Visual examination of these fuels showed no evidence of solid contaminants. Hence the implication is that ordinary fuels seem to behave in a manner similar to well degraded AMK. These results suggest that the filter-ratio method would be even more discriminating if fresh portions of the AMK sample were passed through the same screen several times. These results could then be compared against the same technique used for the base Jet-A.

Filter ratios for the first test series are shown in Figure 19. These results are based on average filter flow-times shown in the preceding figures. The idle result of 23.2 is from the second test series for approximately the same pump speed. These idle results for all three diffusers are considered unacceptable. The poor repeatability of the flow-times is consistent with undegraded fuel based on results from this program. There is no apparent trend with regards to the different diffusers and none would be expected at such poor levels of degradation. Note that the idle result for the second test series using the standard diffuser was no better than that obtained for the other diffusers. Hence, based on overall results one would expect the best results on the number 3 diffuser at all power conditions. For cruise conditions where pump speed is high and flow is modest, fairly good results (1.8 filter-ratio) were obtained for the number 1 (standard) diffuser but substantial better results (1.2 filter-ratio) were obtained with the number 3 diffuser. Takeoff results are the most meaningful in terms of the degree of improvement achieved with the diffuser modifications. This condition represents high speed similar to cruise but a much higher through-flow and brief dwell-time in the pump. As expected, the second diffuser running at a much closer clearance to the impeller, showed a marked improvement. The third diffuser at the same close clearance but with more interaction between the diffuser and impeller blades gave the best results.

Figure 20 shows the relatively simple means for solving the idle problem. For this second test series, pump speed was incrementally increased while maintaining approximate idle flow conditions. Because of lab personnel safety restrictions concerning fuel temperature while the fuel samples were taken, it was necessary to increase flow at higher speeds. Fuel temperature was limited to 200°F and the test results were generally below 150°F. Quite clearly a minimum threshold speed is needed to achieve effective degradation.

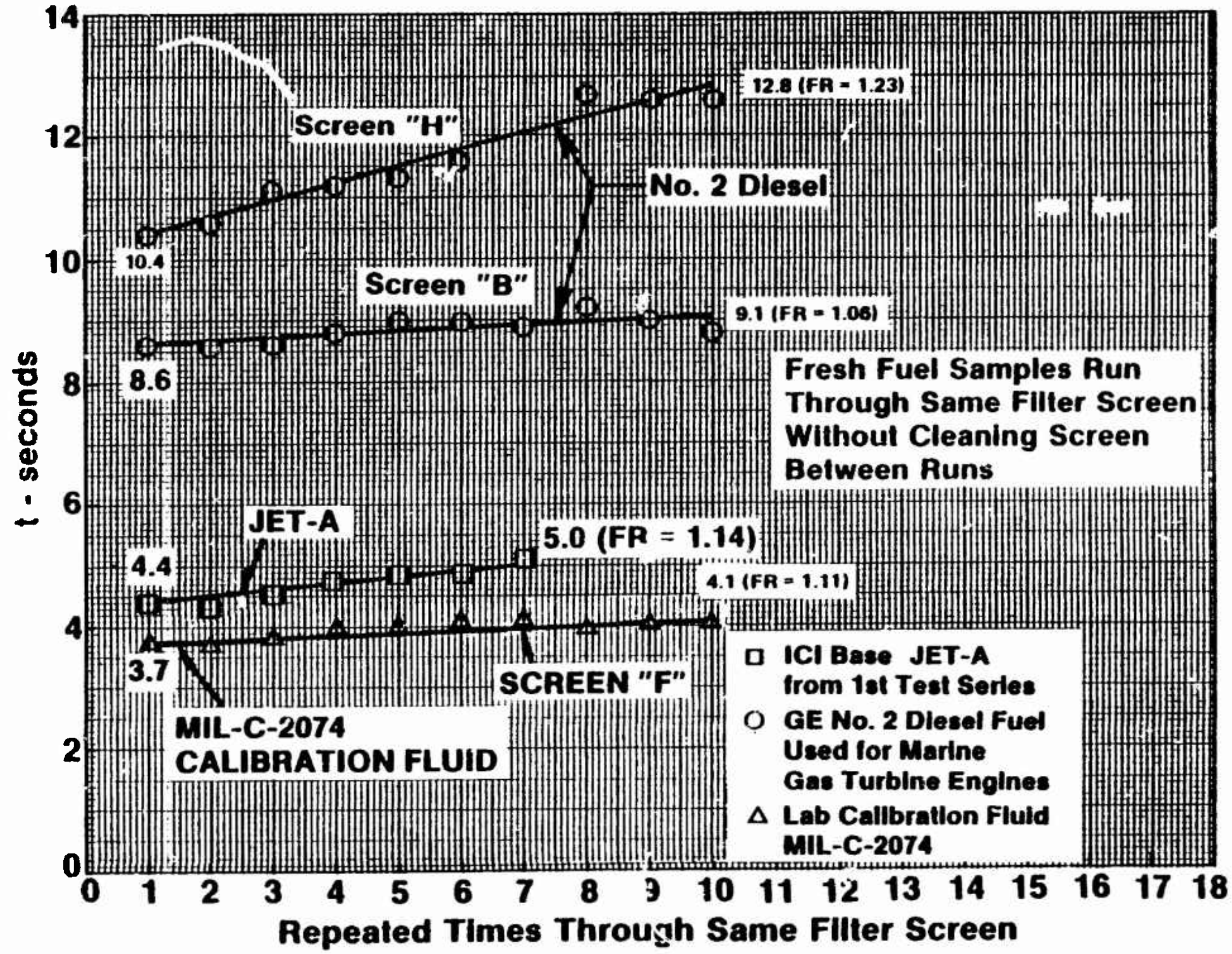


FIGURE 18. APPARENT JELLING CHARACTERISTICS OF GAS TURBINE FUELS FILTER FLOW-TIMES

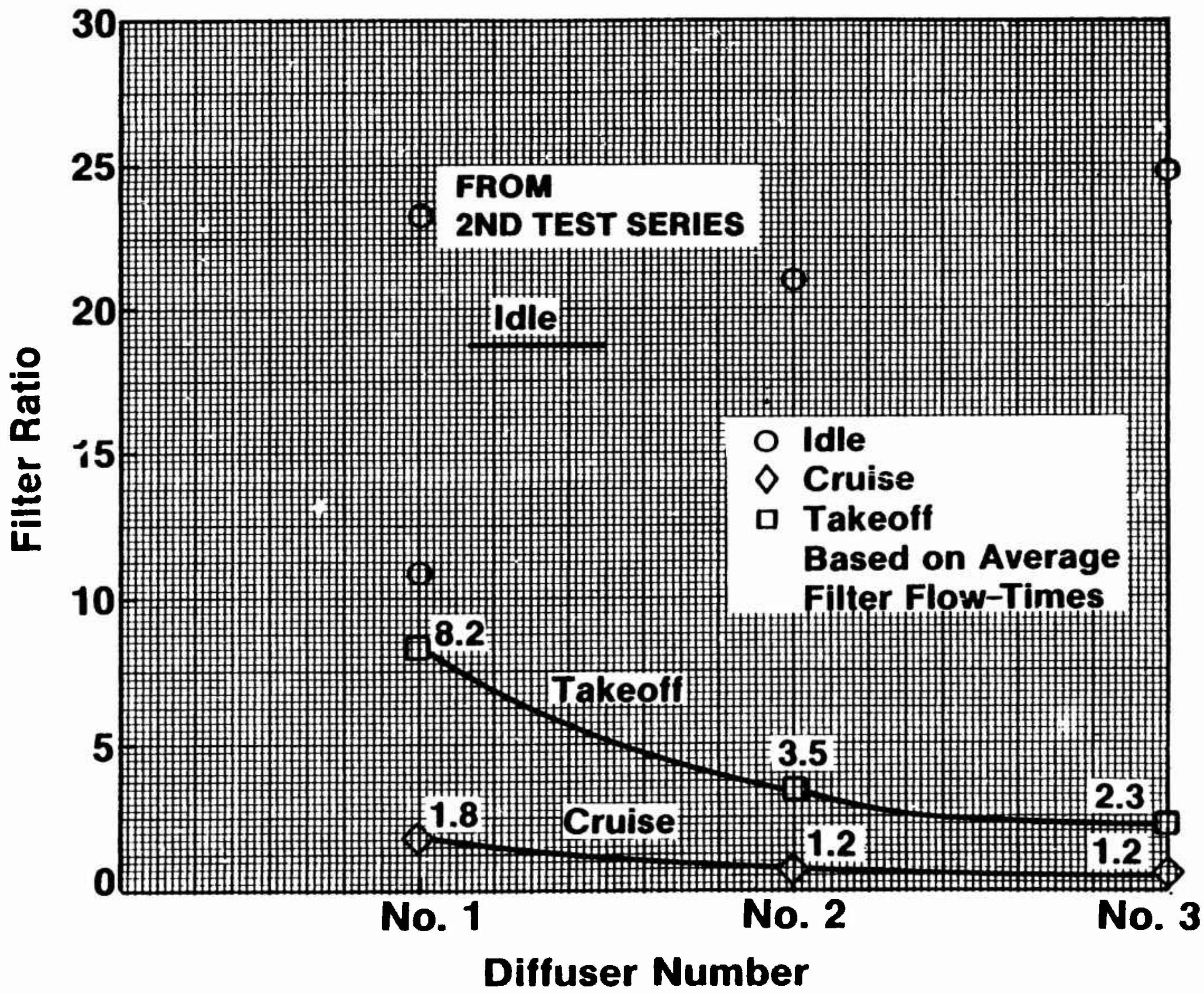


FIGURE 19. FILTER RATIO RESULTS FOR 1st TEST SERIES

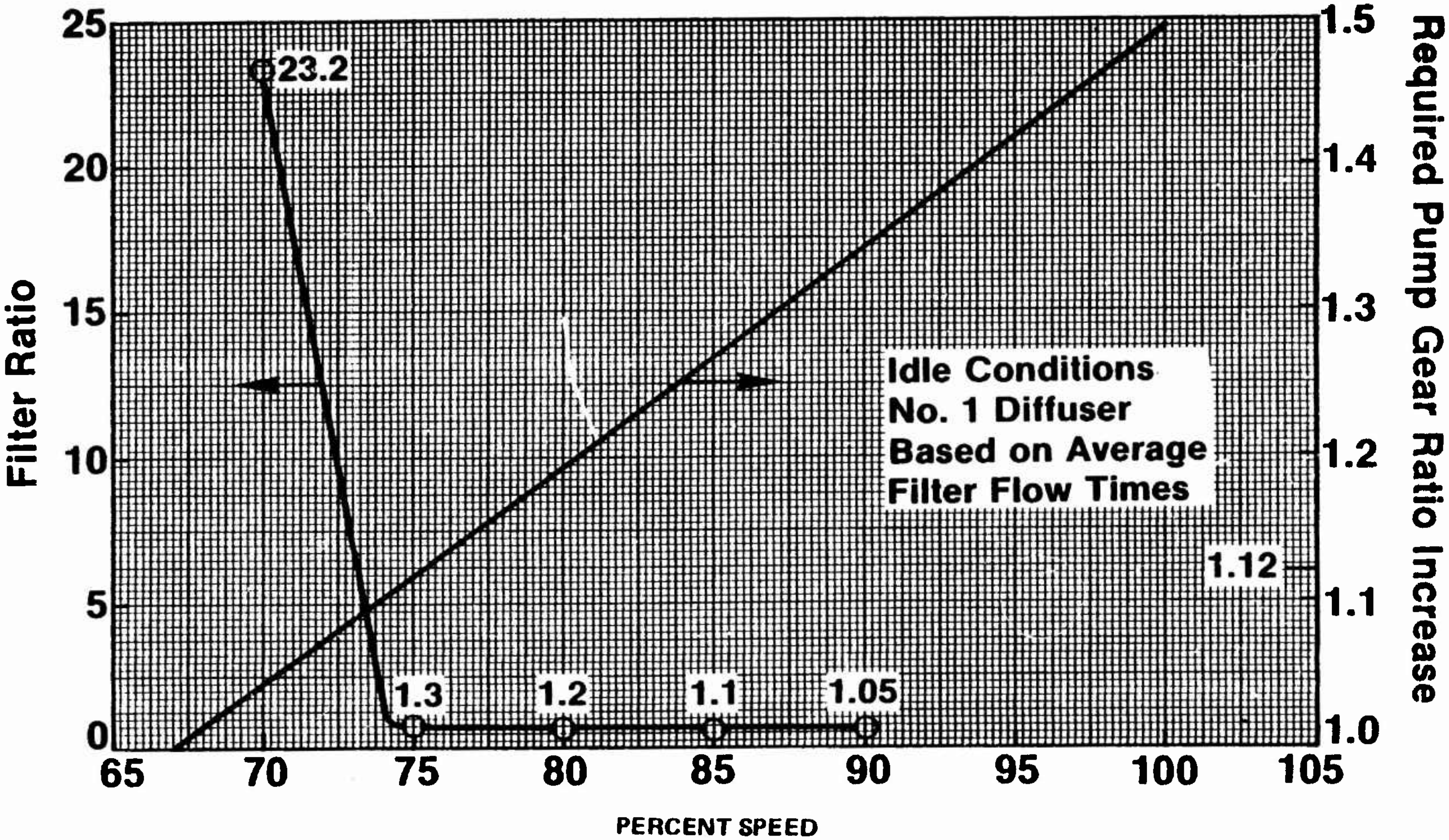


FIGURE 20. FILTER RATIO RESULTS FOR 2nd TEST SERIES

Once this minimum speed (or perhaps critical shearing velocity) is provided, little improvement can be obtained with further increase in speed. A filter ratio of 1.3 would require a 12-percent increase in the base speed (67 percent) of this particular pump. This would be achieved by increasing the pump rated speed (100-percent) by 12-percent.

POWER REQUIREMENTS

Pump input shaft power results are shown in Figure 21. All data has been normalized to required test conditions using centrifugal pump affinity laws in order to account for small differences between test runs. Data was corrected to the test-condition speeds listed in Table 2 based on first-power (flow), second-power (pressure) and third-power (Horsepower) centrifugal pump affinity laws. Input or total power was calculated from test measurements of flow (turbine meter), pressure rise, and temperature rise. Flow meters were calibrated on Jet-A and the results with AMK suggested no significant calibration changes. Measured data are shown in Table 5. Thus, hydraulic power was added to loss power to obtain total power. In nearly all cases the total power obtained by this method using either Jet-A or AMK test data was higher than the predicted power based on the pump manufacturer's predicted shaft power which was originally based on torque meter data. Consequently the results shown in Figure 21 are on the high side when compared to torque data for the same pump design. Table 6 compares measured and predicted power for Jet-A.

TABLE 6. MEASURED AND PREDICTED SHAFT POWER FOR JET-A USING NO. 1 STANDARD DIFFUSER

Point No.	Condition	Predicted Power(1) (HP)	Measured Power(2) (HP)
1	Idle	18.5	17.4
2	Cruise	69.0	76.0
3	Takeoff	100.0	113.2

(1)From pump vendor torque data.

(2)From measured flow, ΔP and ΔT.

Figure 21 shows that the power needed to pump AMK does not differ significantly from the power needed to pump Jet-A. The standard CF6-80 gear pump power requirement is also shown. If an F101 centrifugal pump identical to the one tested were used on the engine in place of the gear pump, the additional power charagable to AMK degradation would be the difference between the gear and centrifugal pumps. It should be noted that this increase in pump power has no direct relationship to degrader performance. For example, the number 3 diffuser is, in all cases, a better degrader than the number 2 diffuser, yet the cruise power is less for number 3 than number 2. Note also that a takeoff filter ratio of 2.3 was achieved for the number 3 diffuser compared with a filter-ratio of 3.5 for number 2, yet the power is the same. In the case of centrifugal pumps used as degraders, the power requirements are predominantly associated with internal losses which do not have a direct relationship to the degrading mechanism.

Normalized (1226 pph) results in Figure 22 shows the effect of F101 pump speed increase at idle conditions on pump input power. These results emphasize that although shaft speed increase is a simple means for achieving

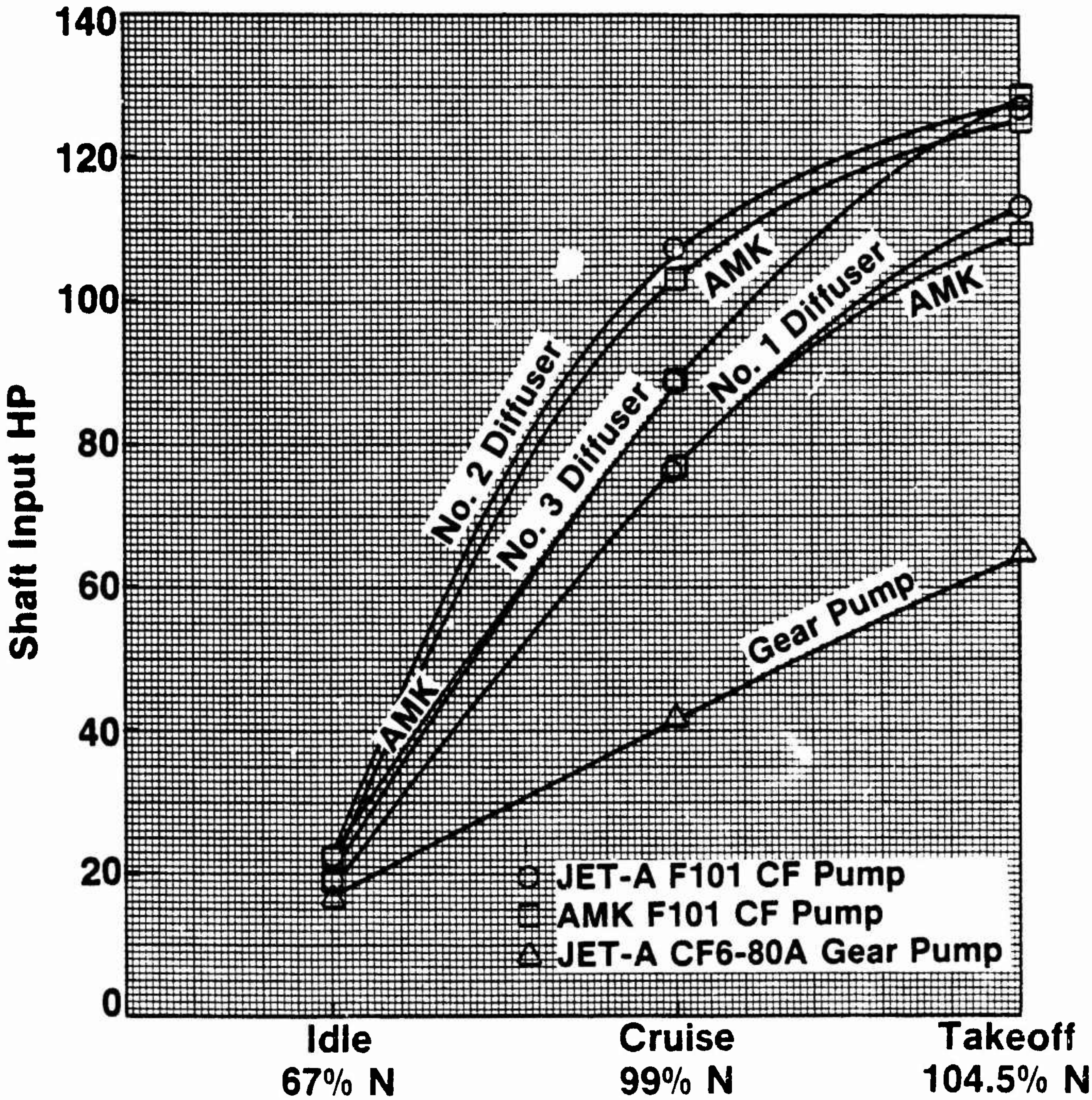


FIGURE 21. PUMP POWER REQUIREMENTS

TABLE 5. PUMP TEST DATA

Test Point	Day	Time	Pump Speed (RPM)	$-P_b-$ Pump Inlet (psig)	$-P_1-$ Pump Discharge (psig)	Lube In (°F)	Lube Out (°F)	$-T_b-$ Pump Inlet Temp. (°F)	$-T_1-$ Pump Outlet Temp. (°F)	Turbine Meter Flow (PPH)	RAMAPO Meter Flow (PPH)	Fuel Sample No.	Remarks
Idle	12/3/81	12:30	16506	40	480	84	99	84	144	1326	1250	N/A	Jet-A - Diffuser #1
Cruise	12/3/81	12:30	24585	40	1020	89	116	84	142	5958	5800	N/A	
Takeoff	12/3/81	12:30	26537	39	1150	83	129	86	114	15396	15500	N/A	
Idle	12/4/81	10:15	16555	40	500	81	97	74	153	1310	1200	N/A	Jet-A - Diffuser #2
Cruise	13/4/81	10:15	24585	[illegible]	1050	83	100	73	160	5584	5800	N/A	
Takeoff	12/4/81	10:15	26015	39	1180	87	110	73	105	15513	15375	N/A	
Idle	12/4/81	13:00	16555	40	510	82	96	73	154	1300	1300	N/A	Jet-A - Diffuser #3
Cruise	12/4/81	13:00	24558	40	1000	83	108	72	142	5634	5650	N/A	
Takeoff	12/4/81	13:00	26015	40	1130	86	119	71	104	15375	15300	N/A	
Idle	12/7/81	04:20	16632	40	500	77	84	72	131	1459	1325	6	AMK - Diffuser #1
Cruise	12/7/81	04:20	24558	39	1040	[illegible]	108	72	128	5991	6000	7	
Takeoff	12/7/81	04:20	26015	39	1160	88	104	71	97	15759	15200	8	
Idle	12/7/81	13:07	16500	40	530	75	89	75	143	1336	1275	10	AMK - Diffuser #2
Cruise	12/7/81	13:07	24530	40	1060	84	90	69	152	5559	4700	11	
Takeoff	12/7/81	13:07	25960	40	1230	94	128	69	100	15395	15100	12	
Idle	12/8/81	08:45	16676	40	480	70	90	68	153	1271	1275	14	AMK - Diffuser #3
Cruise	12/8/81	08:45	24552	40	1020	79	111	68	138	5693	5750	15	
Takeoff	12/8/81	08:45	25988	40	1130	89	126	69	102	15244	15000	16	
Idle	12/11/81	09:15	174[illegible]0	40	530	63	84	64	139	1386	1275	1A	AMK - Diffuser #1
Idle	12/11/81	09:15	18645	40	600	71	99	63	154	1471	1450	2A	
Idle	12/11/81	09:15	19910	40	680	79	110	63	149	2008	2000	3A	
Idle	12/11/81	09:40	21230	40	790	91	109	62	146	2573	2400	4A	
Idle	12/11/81	09:40	22440	40	870	96	124	62	143	3102	3100	5A	
Cruise	12/11/81	09:40	24640	40	1050	99	133	61	118	6040	6100	17	
Takeoff	12/11/81	09:57	26070	40	1170	96	125	60	87	15817	15275	18	

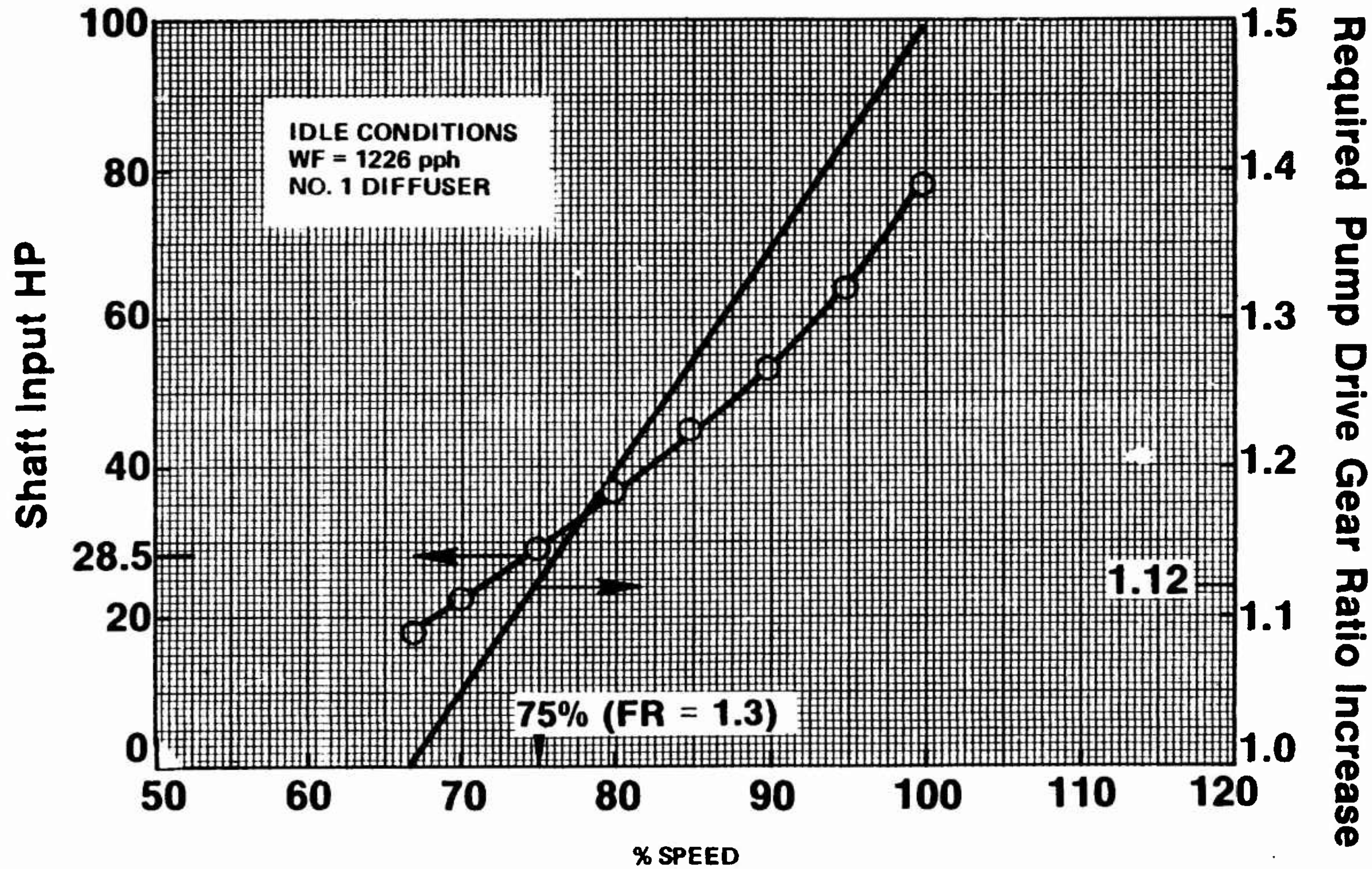
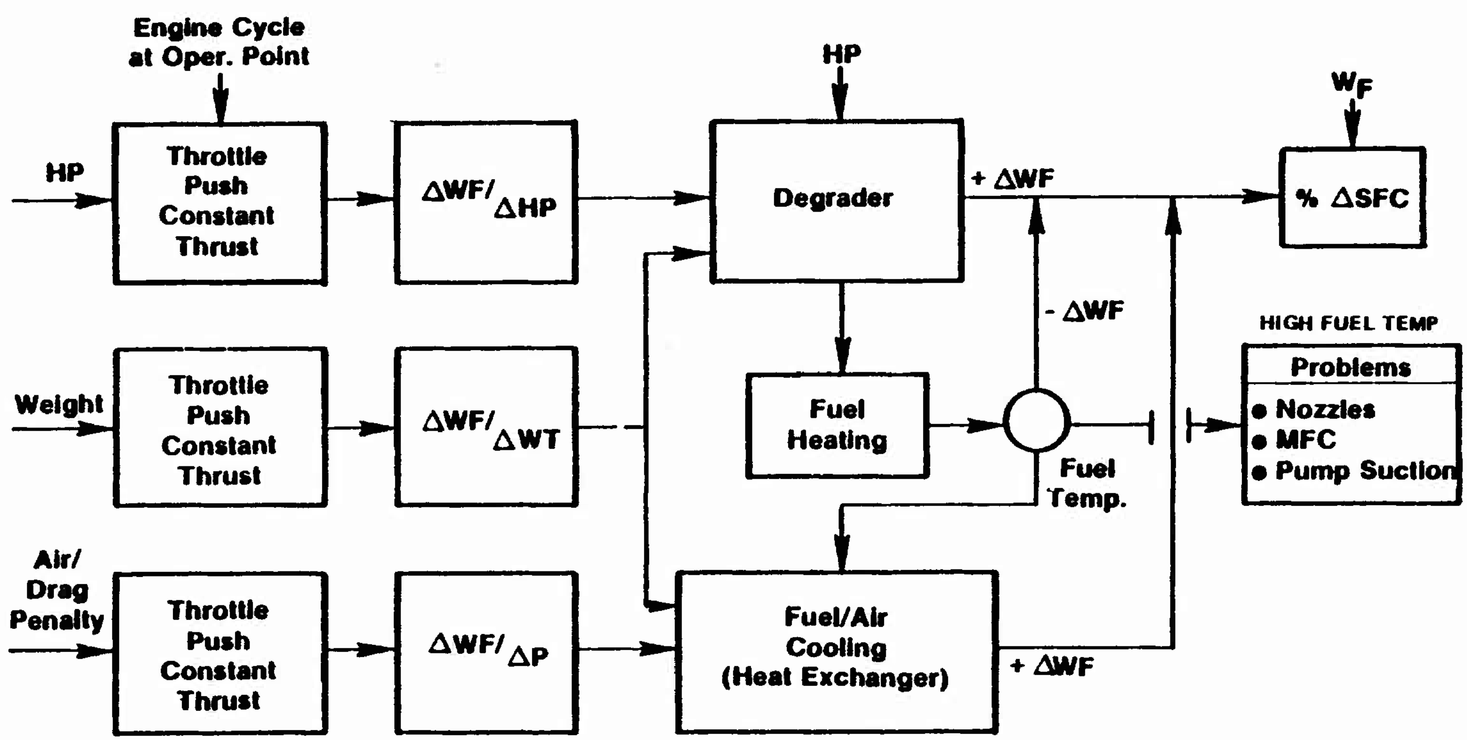


FIGURE 22. PUMP POWER REQUIREMENTS AS A FUNCTION OF SPEED

the desired degradation performance, other pump design changes would be preferable in order to achieve the same "critical shear velocity" effect. This type of change involving the impeller design could not be considered within the scope of this program. Note again that power is not relevant to degrader performance. A reduction in filter-ratio from 23.2 to 1.3 was achieved with a 5-percent speed increase, not as the result of a 6.4 HP power increase.

The effect of pump power and fuel temperature rise on engine fuel burn and SFC is of great concern. At present-day $1.00 per gallon fuel costs, one percent cruise SFC is worth about 800 pounds of engine weight or about $300,000 per engine acquisition cost. In order to assess this power/SFC penalty a thorough understanding of the engine cycle and systems is required. figure 23 shows how this assessment is made. Additional power to degrade AMK requires a throttle advancement. This increases fuel flow by a small amount. However, if fuel temperature limits permit, this additional power goes back into the engine cycle in the form of increased thermal energy of the fuel as it enters the combustor. This results in a reduction of fuel flow. Weight increase or decrease for the pump/degrader also directly affects fuel flow. If too much heat is put into the fuel requiring additional means for engine fuel or lubrication system cooling, fuel flow increases to account of air cooling losses and additional equipment weight.

The aircraft turbojet engine is designed to be a thrust device. Net installed thrust is basically the difference between gross thrust and ram drag; mass flow times velocity in both cases. For the CF6-80 engine at cruise, approximately 40,000 pounds of gross thrust minus 20,000 pounds ram drag leaves about 20,000 pounds of propulsive thrust. Of the 40,000 pounds gross thrust, approximately 30,000 pounds is from the fan. The high pressure (HP) turbine extracts energy from the core flow to drive the compressor and gearbox. The air leaves the HP turbine and passes through the low pressure (LP) turbine which drives the fan. To maintain the same engine thrust and aircraft speed/altitude, gearbox power extracted from the HP turbine results in less power available to the LP turbine, i.e., lower pressure and temperature. This result is compensated for by an increase in fuel flow to the combustor and higher temperature into the HP turbine. Since there is no direct change to the air flow in the engine core or fan, there is little net effect on the major thrust components, i.e., gross thrust and ram drag. If compressor air is bled however, there is a direct loss in HP and LP air flow (turbine power), core exhaust air (thrust), and still a chargeable penalty for the inlet ram drag associated with bringing the bleed flow on board the engine. Generally the use of any engine air for accessory power, or cooling is quite expensive (higher SFC) as compared with gearbox power extraction alone. For this reason fuel cooling needs associated with AMK degrader operation is a bigger concern than gearbox power extraction. For example, 225 HP from the gearbox equates to 0.4 percent of fan air used for cooling. In addition, any gearbox power put into the fuel which <u>does not</u> require cooling results in an energy offset because the warmer fuel provides more energy to the combustor. In other words, parts of the gearbox power extraction is returned to the engine cycle. The most important aspect of degrader power consideration involves an understanding of the engine fuel heat sink so as not to require the addition of any form of fuel cooling.



BIGURE 23. METHOD FOR DETERMINING ENGINE SFC PENALTY

The degrader power issue then comes down to the question of the need for cooling, not shaft power extraction. For those familar with engine accessory cooling, it is well known that low engine power is the problem area because of a lack of adequate heat sink in the fuel, i.e., the fuel flow is too low.

Now considering the matter of the fuel pump, the conventional gear pump is fundamentally undesirable because excess flow capabity at low engine power is wasted in the form of fuel control bypass (recirculation). At idle, where fuel cooling is the major problem, the fuel pump on the CF6-80 engine generates twice as much heat as the entire engine lubrication system.

A conventional high speed centrifugal pump sized for CF6-80 flows and pressures generates about one-half the heat (temperature rise) at idle as the comparable gear pump. Any AMK degrader worthy of practical consideration must be compared on the basis of its low flow power input. In round numbers, one can afford to derate the low flow efficiency of the conventional pump by a factor of two and still be no worse off than the present-day gear pump. Shown as follows are typical gear and centrifugal pump power requirements and fuel temperature rise for JET-A fuel.

	Takeoff	Cruise	Idle Descent
CF6-80A			
Flow, pph	15637	5506	550
Speed, %	104.5	98.6	73.8
Gear Pump			
Shaft HP	65.0	41.0	19.5
ΔT, ^oF	14	34	168
Centrifugal Pump			
Shaft HP	51.7	25.7	8.55
ΔT, ^oF	10	20	77

Figures 24 and 25 show power and SFC penalty calculated on the basis of gearbox power alone and also with increase in fuel thermal energy. With no improvement to the F101 centrifugal pump as tested, auxiliary air cooling would be required but this result (SFC penalty) is not included. The immediate program was only intended to show the feasibility of the centrifugal pump as a replacement to the gear pump for use with AMK. Refinements are still needed in order to achieve the desired level of input power. Shown in these figures is an estimate of the best-power requirement needed for a centrifugal pump on the CF6-80 engine suitable for use with AMK. This pump would be sized for the 41 gpm requirement of this engine rather than the 210 gpm required for the F101 engine augmentor. As can be seen in Figure 25, such a pump/degrader combination might actually reduce engine fuel burn and improve SFC.

The new centrifugal (CF) pump whose estimated power requirements are shown in Figures 24 and 25 is based on theoretical considerations derived from the results of this program. The basis for these predictions evolves partially from the fact that the results of this program were in agreement with prior analysis and theory. It had been predicted that AMK degrading performance would improve with the planned successive modifications to the diffuser. It

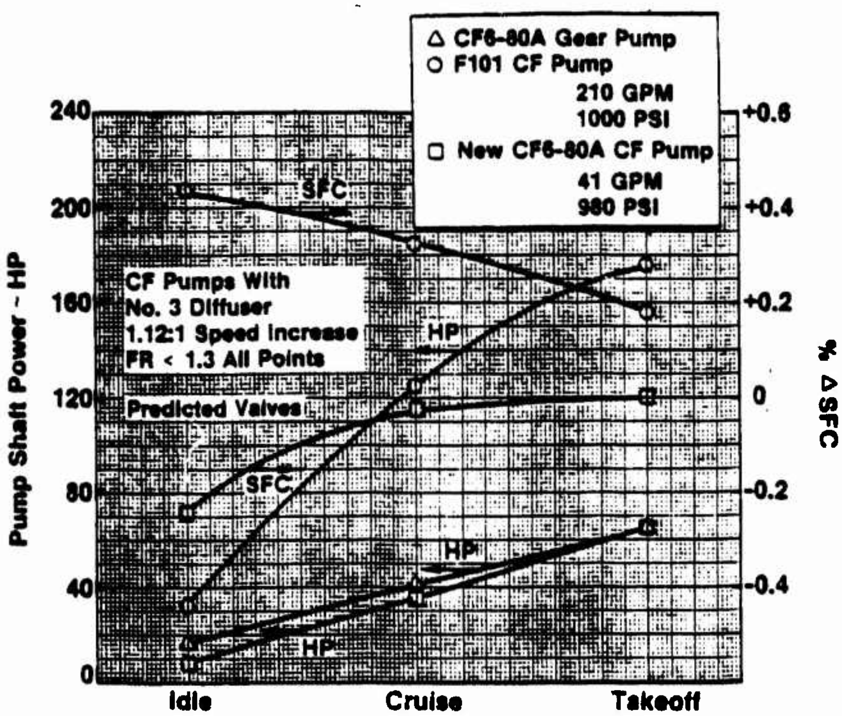


FIGURE 24. PUMP POWER AND EFFECT ON SFC WITHOUT FUEL HEATING

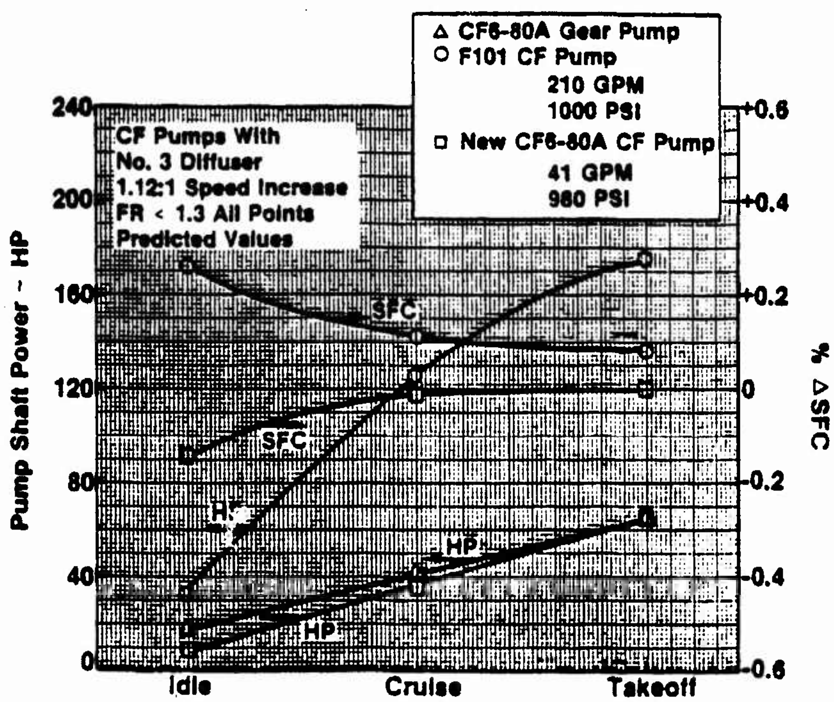


FIGURE 25. PUMP POWER AND EFFECT ON SFC WITH FUEL HEATING

had also been expected that takeoff flows would be the most difficult. The precise minimum speed for effective degradating was not however known nor was it realized that such a sharp break in filter-ratio would occur with slight increase in idle pump speed.

In terms of power requirements, these results take on significance. All centrifugal pumps distribute input shaft power in three areas:

1. Useful power in the form of flow and static pressure rise.

2. Losses associated with molecular shear stress.

3. Losses associated with increase and decrease of static and dynamic pressure.

Further, losses are always a combination of 2 and 3. The categories of predominant loss associated with a high pressure centrifugal pump used on a jet engine are disc friction, internal recirculation and hydraulic losses. Disc friction is a major loss but contributes vertually nothing to AMK degradation. Recall that a threshold shearing stress is required. Except for the impeller tip and diffuser region, recirculation and hydraulic losses contribute vertually nothing to AMK degradation. For the F101 impeller at speeds between 18,000 and 26,000 rpm it is estimated that only a small portion of total pump losses are in any way involved in the degrading process and these losses occur between the impeller tip and the diffuser inlet.

The key to this issue is to reduce overall losses but enhance (increase) losses which contribute to degrading AMK. This involves consideration of the principle concerns surrounding the use of a high speed centrifugal pump for the main fuel system. These issues are:

1. High Speed - Reduces losses and improved degradation but increases suction boost requirements.

2. Stability - Fuel system considerations outside the pump can permit relaxation of stability requirements. This can permit degradation improvement.

3. Recirculation - Must be enhanced in the region where it does the most good; at the impeller tip. Other recirculation losses must be reduced.

Following along lines of conventional pump theory but considering the above and the techniques applied during this program, it is possible to predict the performance of a more optimized pump. This was done and yielded the results shown in Figures 24 and 25. Note that it is only coincidental that gear and centrifugal pump power is the same at takeoff.

DISCHARGE PRESSURE PULSATIONS

When considering the use of any new device in the engine fuel system, it is important to assess its effect on fuel metering dynamics, combustion stability and component structural strength. Low frequency pressure pulsations can cause the fuel metering valve to track the change in ΔP which can lead to engine speed/power oscillations or combustion instability. High frequency

pressure fluctuations can promote destruction reasonant vibration of servo valves, screens, heat exchanger tubes and other small parts. Therefore, it was decided to measure fuel pump discharge static pressure pulsations with Jet-A, AMK and the three different diffusers.

Pressure pulsation results are shown in Figure 26. A Kulite high frequency pressure transducer was installed at the pump discharge. Total pressure pulsation was recorded on magnetic tape and then run through a spectral analyzer to determine pressure pulsation amplitude at frequencies from 50 to 10,000 Hz. The results shown in the figures are in terms of peak pressure, that is half-amplitude of the pressure fluctuation about the steady-state static pressure level. The values below 500 Hz are system influences and not the result of the high speed pump impeller. In the higher frequency region where differences might be expected, there is no evidence of any potential problems. As shown in Figure 26C, the number 3 diffuser showed the highest level of pressure pulsation at impeller blade and diffuser vane coupling frequencies (6500 Hz at takeoff) but the amplitude is small and of no consequence.

These measurements of pump discharge pressure stability also served as a means for verifying that no air evolution or vaporous cavitation was induced in the pump as the result of the diffuser modifications. Both of these phenomina produce very unstable (uncontrollable) pressure and flow from a centrifugal pump, particularly a low specific speed design such as the F101. Air evolution from jet fuel even at relatively high pressure is a particular problem requiring special vapor to liquid (V/L) tests as part of the engine certification. The V/L for tests is usually generated by throttling at pressures much higher than vapor pressure. Jet-A has low vapor pressure, 0.1 psia versus 2.7 for Jet-B (JP-4) at 100°F, but Jet-A holds just as much air. When air saturated jet fuel is taken to altitude, reduction in pressure and cooling causes the air along with higher-boiling point fuel vapors to evolve. Then when the aircraft altitude is reduced, the fuel has "Weathered" and no longer easily evolves air or vapor. Consequently, it would not be desirable to have a dependency on air/vapor evolution as part of the pump AMK degrading mechanism. It might also be noted that there was no evidence of cavitation or other erosion on any parts of the pump following these tests. The diffuser was uncoated 6061-T6 aluminum.

ADDITIONAL FUEL LAB RESULTS

AMK property data measured by ICI Americas Inc. is shown in the Appendix of this report. The results of General Electric Company fuel property measurements are shown in Table 7. Water content of the residual AMK in the test supply tank was determined at the completion of all tests. Using the General Electric Company preferred technique (not Carl-Fisher method) the total water content was found to be only 6 parts per million. The method involves a calcium hydride test at room temperature where H_2 and H_2O are measured from the calcium hydride mix. The procedure is described in the Appendix.

Three filter screens were checked using the bubble-point technique to verify micron rating. The results were as follows:

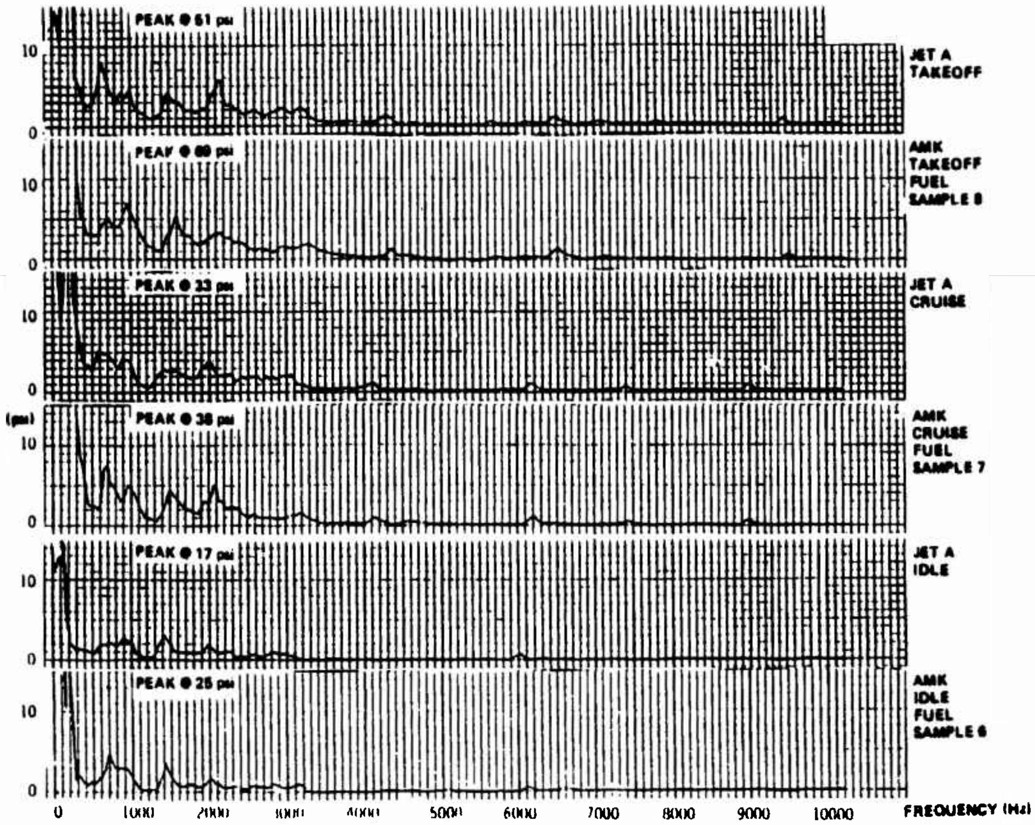


FIGURE 26A. PUMP DISCHARGE PRESSURE PULSATION, DIFFUSER #1

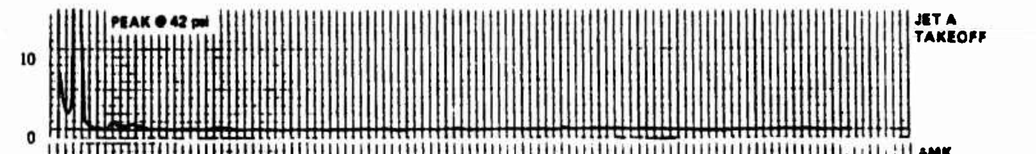


FIGURE 26B. PUMP DISCHARGE PRESSURE PULSATION, DIFFUSER #2

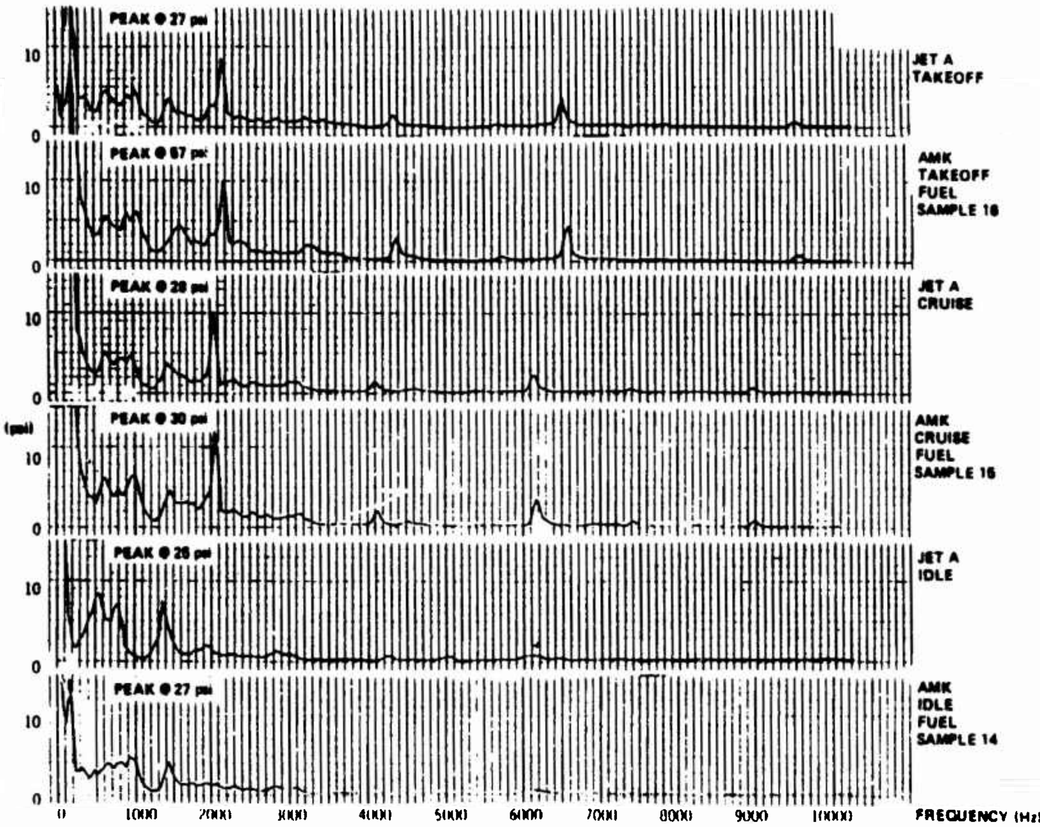


FIGURE 26C. PUMP DISCHARGE PRESSURE PULSATION, DIFFUSER #3

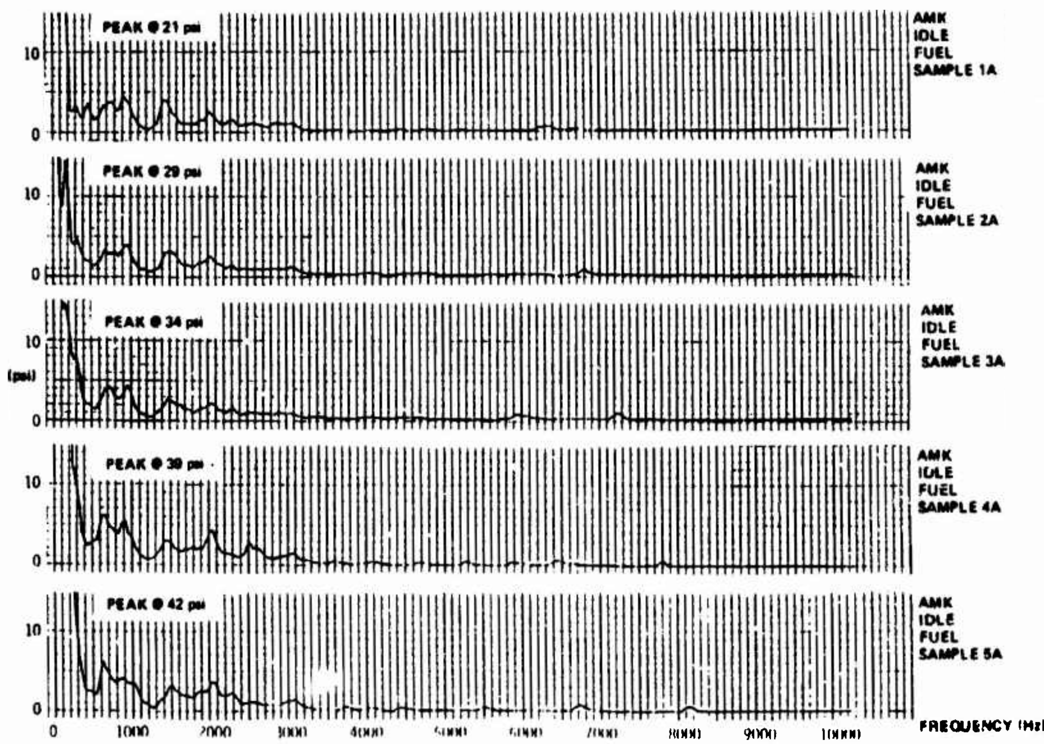


FIGURE 26D. PUMP DISCHARGE PRESSURE PULSATION, DIFFUSER #1

TABLE 7. FUEL PROPERTY MEASUREMENTS

Screen	Absolute Rating (1st Bubble)	Nominal Rating (Many Bubbles)
1	22 microns	19
2	19	16
3	19	16

It was concluded that the rating for the screen was 17 microns based on the nominal rating results.

RMH Fuel Batch No.	Specific Gravity		Viscosity[1]	
Jet-A 11005	0.8136	60°F/60°F	2.10 CS	77°F
	0.8090	72°F		
	0.8074	77°F		
1-177	0.8153	60°F/60°F	3.40 CS	77°F
	0.8107	72°F		
	0.8088	77°F		
1-180	0.8154	60°F/60°F	3.34 CS	77°F
	0.8108	72°F		
	0.8089	77°F		
1-181	0.8155	60°F/60°F	3.24 CS	77°F
	0.8105	73°F		
	0.8090	77°F		

(1)200 Size Viscometer (Cannon-Fenske Routine).

CONCLUSIONS

The Antimisting Fuel Degrader Investigation program results lead to the following conclusions:

1. The high speed centrifugal pump can achieve very high levels of AMK degradation.

2. Modification of the impeller diffuser can significantly enhance degradation capability without detrimental effect on pressure stability and power requirements, nor dependency on air/vapor evolution.

3. Diffuser modification is required to achieve significant levels of degradation at high flows when fluid dwell time is low.

4. A critical or minimum shearing velocity effect is needed for the onset of effective degradation even at low idle flows.

5. A relationship exists between the degree of difficulty for effective degradation, pump speed and flow. Speed or a shearing velocity effect appears to be the major influence.

6. Inadvertent degradation of on-line fuel samples can be avoided by using a technique which throttles the fuel at the discharge of the sampling system.

7. Filter-ratio is an effective means for obtaining fast low-cost initial evaluation of an AMK degrader device. In the future however, the same screen should be used to compare the AMK sample and base Jet-A flow-times since screen-to-screen variations has a significant influence of filter-ratio.

8. Except at the more highly degraded levels of degradation filter ratio results tend to be inherently non-repeatable. Hence for marginally degraded AMK (filter-ratio greater than 10), single values of filter-ratio are questionable from a repeatability standpoint.

9. The accuracy of filter-ratio as a measure of proximity to Jet-A characteristics was not determined from this program. However, in terms of trend, repeatability and consistency with expected results, it is concluded that degradation requires a filter-ratio value below 10.

10. At room ambient temperatures, the calculated (or estimated) power required to pump AMK in a centrifugal pump is not significantly different than that required to pump Jet-A.

11. No specific relationship was found between the power required to degrade AMK and the power used by the pump to produce flow and pressure.

12. Even for an oversized pump such as the F101, the projected SFC penalty for engine gearbox power extraction is low (0.32% SFC increase relative to gear pump not counting the energy returned to the cycle by fuel heating). The predominant SFC issue is the need for fuel cooling or lack of fuel heat sink for other systems.

13. Based on these initial results relative to degradation capability and fundamental consideration of pump design, a centrifugal pump can be developed which would yield insignificant SFC penalty and provide adequate degradation. Further, such a pump can be expected to achieve this result without compromise to the design, operation, weight, cost, or reliability of the engine fuel system.

REFERENCES

1. A Fiorentino, R. DeSaro, T. Franz, United Technologies Corporation, "An Assessment of the Use of Antimisting Fuel in Turbofan Engines", FAA-CT-81-58, June 1981.

2. R.J. Mannheimer, Southwest Research Institute, "Degradation and Characterization of Antimisting Kerosene (AMK)", FAA-CT-81-152, June 1981.

APPENDIX

1. ICI FUEL PROPERTY DATA FOR TEST FUEL

2. CALCIUM HYDRIDE WATER TEST PROCEDURE

ICI Americas Inc.

Chemical
Engineering
Laboratories

October 26, 1981

FAA/Tech Center
c/o General Electric Co.
Building 703, ATTN: David Necamp
Cell 44 Rear
Evandale, OH 45215

Dear Mr. Necamp:

We shipped to you on October 26, 1981, 18 drums (5,940 pounds net) of AMK-FM9-030 and one pail (30 pounds net) of Jet A Fuel against our order number 019370-01.

Analysis and identification of this material is as follows:

Lot Number	RMH 1-177	RMH 1-180	RMH 1-181
Number of Drums	2	8	8
Solids, %	0.31	0.31	0.30
Flow Cup, ml/30 sec	2.7	2.4	2.5
Viscosity @ 25°C, cp.	3.1	3.9	3.7
Clarity	Clear	Clear	Clear

Sincerely,

ICI AMERICAS INC.

RM Harris

R. M. Harris
Semi-Works Production
Chemical Engineering Laboratories

RMH:aer

New Castle, Delaware 19720 (302) 575-4600

ICI Americas Inc.

Chemical
Engineering
Laboratories

December 1, 1981

General Electric Co.
Building 703, ATTN: David Necamp
Cell 44 Rear
Evandale, OH 45215

Dear Mr. Necamp:

We shipped to you on December 1, 1981, 8 drums (2,640 pounds net) of AMK-FM9-030 and one pail (33 pounds net) of Jet A Fuel against our order number 042905-01.

Analysis and identification of this material is as follows:

Lot Number	RMH 1-213
Solids, %	0.30
Flow Cup, ml/30 sec.	2.3
Viscosity @ 25 C, cp.	2.90
Clarity	Clear
Base Fuel Lot No.	RMH 11005

Sincerely,

ICI AMERICAS INC.

RMHarris

R. M. Harris
Semi-Works Production
Chemical Engineering Laboratories

RMH:aer

ANALYTICAL TEST METHOD

GASOMETRIC DETERMINATION OF WATER IN ORGANIC LIQUIDS WITH CALCIUM HYDRIDE

This method for the determination of water in organic fluids is based on the measurement of the hydrogen gas evolved when calcium hydride reacts with said water. Calcium hydride reacts with water according to equation I.

$$\text{I.}\quad CaH_2 + 2H_2O \longrightarrow Ca(OH)_2 + 2H_2$$

Using the relationships shown in equation I, it is possible to construct a sample apparatus which will measure the volume of gas evolved when calcium hydride reacts with the water dissolved in the fluid. This method for determining water in organic liquids is capable of high precision if precautions are taken to properly thermostat the apparatus and allow a long enough time to insure complete reaction of the hydride and water. However, for our purpose, sufficient precision is reached by a relatively simple procedure.

Apparatus

1. Gas measuring apparatus, including a gasometer, a reaction flask (3 or 4 should be kept on hand) and calcium hydride holder. A sketch of a suitable apparatus is appended to this test method.

2. Magnetic stirrer with several teflon covered stirrers.

3. Ten ml. syringe (or larger if necessary) with 4" 20 ga. needle (3 or 4 of these should be available).

4. Triple beam balance which gives direct readings to the second decimal place.

5. 150° oven.

6. Gas drying tube, filled with Drierite.

Procedure

1. The reaction flask is dried in the oven at 150°C for a least one hour. The magnet stirrers should be dried on a watchglass in the oven one hour. A syringe is also dried in the oven for one hour. It should be taken apart for drying.

2. While the reaction flask is drying, fill the calcium hydride holder about one-half full with calcium hydride and cork it up.

3. Grease all joints with silicone stopcock grease.

4. Put one of the dry magnetic stirrers into the dry reaction flask.

5. With the reaction flask in place, purge with nitrogen until cool. Allow the nitrogen to enter by the calcium hydride inlet and out by the open outlet stopcock.

NOTE 1 - The gas drying tube should be put into the line between the nitrogen valve and the gasometer.

NOTE 2 - To hasten the cooling and to keep a more even temperature in the flask, the flask should be immersed in a container of water at room temperature.

NOTE 3 - Remove the flask from the oven and immediately connect to the apparatus.

6. Remove the dried syringe from the oven and assemble it.

7. With the syringe, withdraw a 10 ml. sample (or larger) of the fluid to be tested. Discard this sample and draw a second 10 ml. sample. Plate a small rubber stopper on the needle and weigh the loaded syrings. (Weighing should be done to the nearest 0.01 grams).

8. Stop nitrogen purge and discharge the syringe sample into the reaction flask thcrugh the inlet tube.

9. Uncork the calcium hydride holder and place in the inlet tube.

10. Start stirrer and allow to stir for 5 minutes. While stirring adjust the level of the mercury in the microburette to zero.

    NOTE - Dired toluene may be used as a solvent in the case of high-viscosity fluids.

11. During the stirring time, weigh the emptied syringe and rubber stopper and determine the weight of sample.

12. Turn the outlet stopcock to closed position. Lower mercury leveling bulb to apply slight vacuum on system. Any leaks will show themselves by a gradual leveling of the manometer fluid.

    NOTE - To increase the sensitivity of the manometer to small pressure charges, tetrabromethane tinctured with methyl violet is used.

13. Rotate the calcium hydride holder so the hydride falls into the reaction flask.

14. A few seconds after adding the calcium hydride to the fluid, gas evolution will begin and the mercury will be depressed. Lower the mercury leveling bulb at such a rate as to keep the two manometer levels approximaterly even.

15. When there is no further evolution of hydrogen, move the mercury leveling bulb until the manometer is leveled and record the volume of gas. Before recording the final volume recheck the temperature of the cooling beaker. It if is not at room temperature adjust with tap water. Then allow enough time for the reaction flask to come to room temperature. Note that the stirrer may cause the cooling beaker to rise in temperature. If this be the case, do not use the stirrer as a stand for the beaker during the final cooling.

16. Calculate the water in parts per million in the following way.

Since equation (1) shows one mole of hydrogen generated for one mole of water:

$$\frac{\text{ml. } H_2 \times 804}{\text{gm. sample}} = \text{P.P.M. } H_2O$$

For more exact measurements, temperature and pressure factors are included:

$$\frac{\text{ml. } H_2 \times 288.8 \, \frac{\text{P mm}}{T^{o} \text{ (Kelvin)}}}{\text{gm. sample}} + \text{P.P.M. } H_2O$$

Precautions

Since silicone fluids pick up water very rapidly, particularly when dry, extreme precautions must be taken. Dry the reaction flask thoroughly and be certain that all syringes for transferring tetramer are thoroughly dry. Keep the apparatus open to the atmosphere for as short a time as possible during all opeations. Since calcium hydride reacts vigorously with water, use caution when disposing of unreacted hydride in the reaction flask. Shake out most of the excess into the sink with water running in the sink. Use a rapid stream of cold water to wash out the flask and finally rinse the flask twice with acetone. Flush the acetone vapors from the flask with nitrogen before putting the flask in the oven.

GAS MEASURING APPARATUS